SR 3 MP 52.21 Johnson Creek to Liberty Bay (WDFW ID 991744): Preliminary Hydraulic Design Report

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1 Introduction

To comply with United States et al. vs. Washington et al., No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 through 23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the State Route (SR) 3 crossing of Johnson Creek to Liberty Bay (Johnson Creek) at milepost (MP) 52.21 within WSDOT's Olympic Region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier [ID] 991744) and has an estimated 3,445 linear feet of habitat gain (WDFW 1999).

Per the federal injunction and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT evaluated the crossing and is proposing to replace the existing crossing structure with a structure designed using the unconfined bridge design methodology.

The crossing is located in Kitsap County, 0.5 mile northwest of Poulsbo, Washington, in Water Resources Inventory Area 15 (Washington State Department of Ecology [Ecology] n.d.). The highway runs in a northeast-southwest direction at this location and is about 1.5 miles from the confluence with Liberty Bay. Johnson Creek generally flows from northwest to southeast, beginning approximately 3,700 feet upstream of the SR 3 crossing (Figure 1).

The proposed project will replace the existing 36-inch-diameter, 211-foot-long, corrugated metal pipe (CMP) with a structure designed to accommodate a minimum hydraulic width of 20 feet. The proposed structure is designed to meet the requirements of the federal injunction using the unconfined bridge design criteria (structure type is not being recommended by WSDOT Headquarters [HQ] Hydraulics and will be determined by others at future design phases), as described in WDFW's *Water Crossing Design Guidelines* (WCDG; Barnard et al. 2013). This design also meets the requirements of WSDOT's *Hydraulics Manual* (WSDOT 2022).

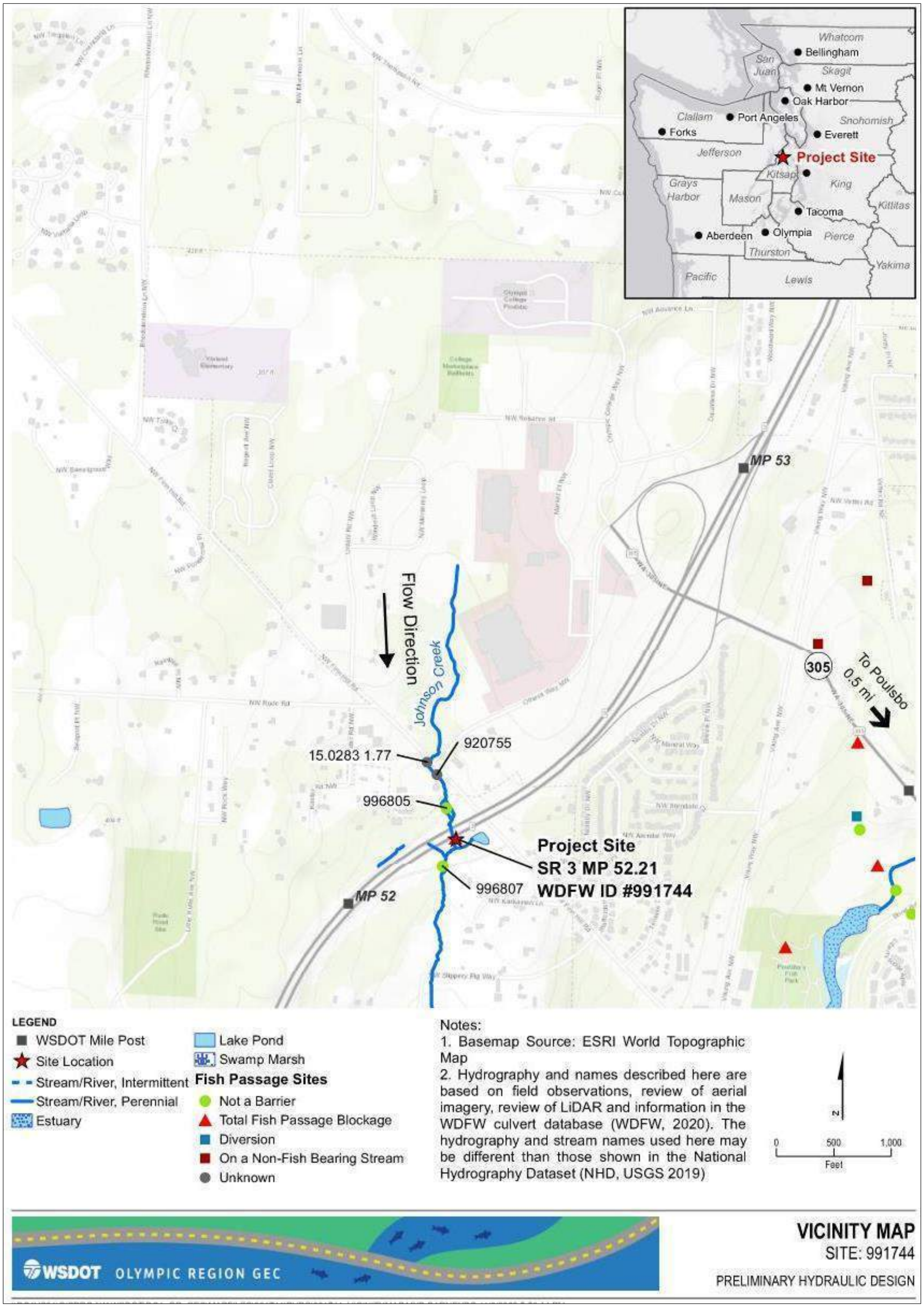


Figure 1: Vicinity map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, regulatory floodplains, fish presence, site observations, wildlife crossing priority, and geomorphology. This was performed using a site visit and desktop research with resources such as the U.S. Geological Survey (USGS), Federal Emergency Management Agency (FEMA), and WDFW and past records such as observations, maintenance, and fish passage evaluation.

2.1 Site Description

The July 1999 WDFW Level A Culvert Assessment Report found that the existing corrugated steel culvert is a full fish barrier due to slope (reported at 2.9 percent) with a 0 percent passability (WDFW 1999). According to Figure 3.19 of WDFW's *Fish Passage Inventory, Assessment, and Prioritization Manual* (2019), this crossing is considered a slope barrier due to the lack of embedment and slope greater than 1 percent. This negatively affects fish habitat by limiting the movement of sediment and woody material. No streambed material was reported in the crossing. The actual culvert slope was measured at 3.4 percent, per recent WSDOT survey (2021; Appendix D). WDFW's report deemed this area a significant reach that could gain 3,724 square feet of spawning habitat, 3,584 square feet of rearing habitat, and a total length of 3,445 feet of potential habitat by improving the SR 3 crossing (WDFW 1999).

The site is not classified as a Chronic Environmental Deficiency or as a failing structure by WSDOT HQ Hydraulics. Maintenance and emergency repair history for this crossing was requested, but WSDOT indicated there none are for this crossing. The project is not within a special flood hazard area or mapped FEMA floodplain, as shown in Appendix A. The area is designated as Zone X - area of minimal flood hazard (FEMA 2017).

2.2 Watershed and Land Cover

Johnson Creek[1] flows in a southeasterly direction, crosses SR 3 at MP 52.21, and flows into Liberty Bay about 1.5 mile downstream of the SR 3 crossing. Johnson Creek does not include any major named tributaries upstream of the SR 3 crossing. A combination of gridded light detection and ranging (LiDAR) topography and field observations by Jacobs Engineering Group Inc. (Jacobs; the design team) were used to define the watershed area that drains to the outlet of the existing structure (Figure 2), resulting in a delineated watershed area of 431 acres (0.67 square mile). As shown on Figure 2, the watershed is broken into three subwatersheds: Subwatershed 1 (388 acres) contributes to Johnson Creek and the structure inlet, and Subwatershed 2 (29 acres) and Subwatershed 3 (14 acres) drain at the outlet.

The Johnson Creek watershed ranges in elevation from 420 to 240 feet using NAD83 (North American Datum of 1983) as the vertical datum. The watershed consists of fluted-shaped terrain that is moderately sloped in the western portion of the watershed and fairly low slope along the eastern boundary in developed areas (Figure 3). Land use was evaluated using the National

[1] Hydrography and names described herein and shown on Figure 1 are based on field observations, aerial imagery review, LiDAR review, and information in the WDFW culvert database (WDFW n.d.-a). The hydrography and stream names used herein may be different than those shown in the National Hydrography Dataset (USGS 2019).

Land Cover Database (Multi-Resolution Land Characteristics Consortium [MRLC] 2019a), National Urban Imperviousness Database (MRLC 2019b), and visual interpretation of aerial imagery (ESRI n.d.). Most of the southwest portion of the watershed is forested area and pasture with single-family residences interspersed, the southeast portion is predominantly developed with various levels of intensity, and the northern portion is predominantly forest with single-family residences interspersed. The land cover is about 35 percent forest and 63 percent developed (Figure 4), with the remainder consisting of barren land, wetlands, pasture/hay, and scrub/shrub, as identified in Table 1. Total impervious area is approximately 25 percent of the watershed, based on analysis of National Urban Imperviousness Dataset (MRLC 2019b).

Table 1: Land cover (MRLC 2019a)

Land Cover Class	Basin Coverage (%)
Barren Land	0.4
Deciduous Forest	0.8
Developed, High Intensity	5.9
Developed, Low Intensity	19.7
Developed, Medium Intensity	17.2
Developed, Open Space	20.4
Emergent Herbaceous Wetlands	0.1
Evergreen Forest	30.2
Grassland/Herbaceous	0.4
Mixed Forest	2.4
Open Water	0.0
Pasture/Hay	0.2
Shrub/Scrub	0.9
Woody Wetlands	1.4

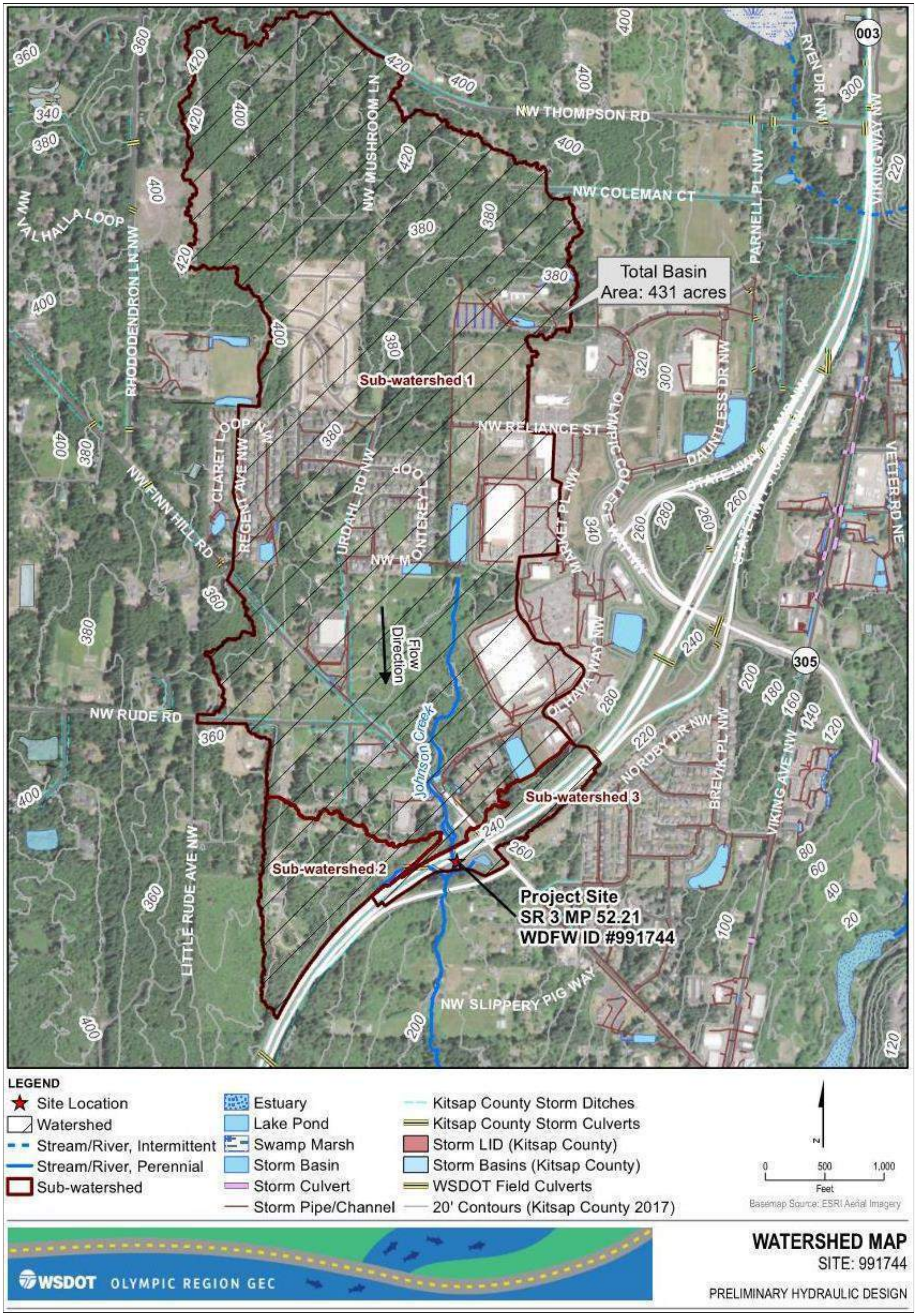


Figure 2: Watershed map

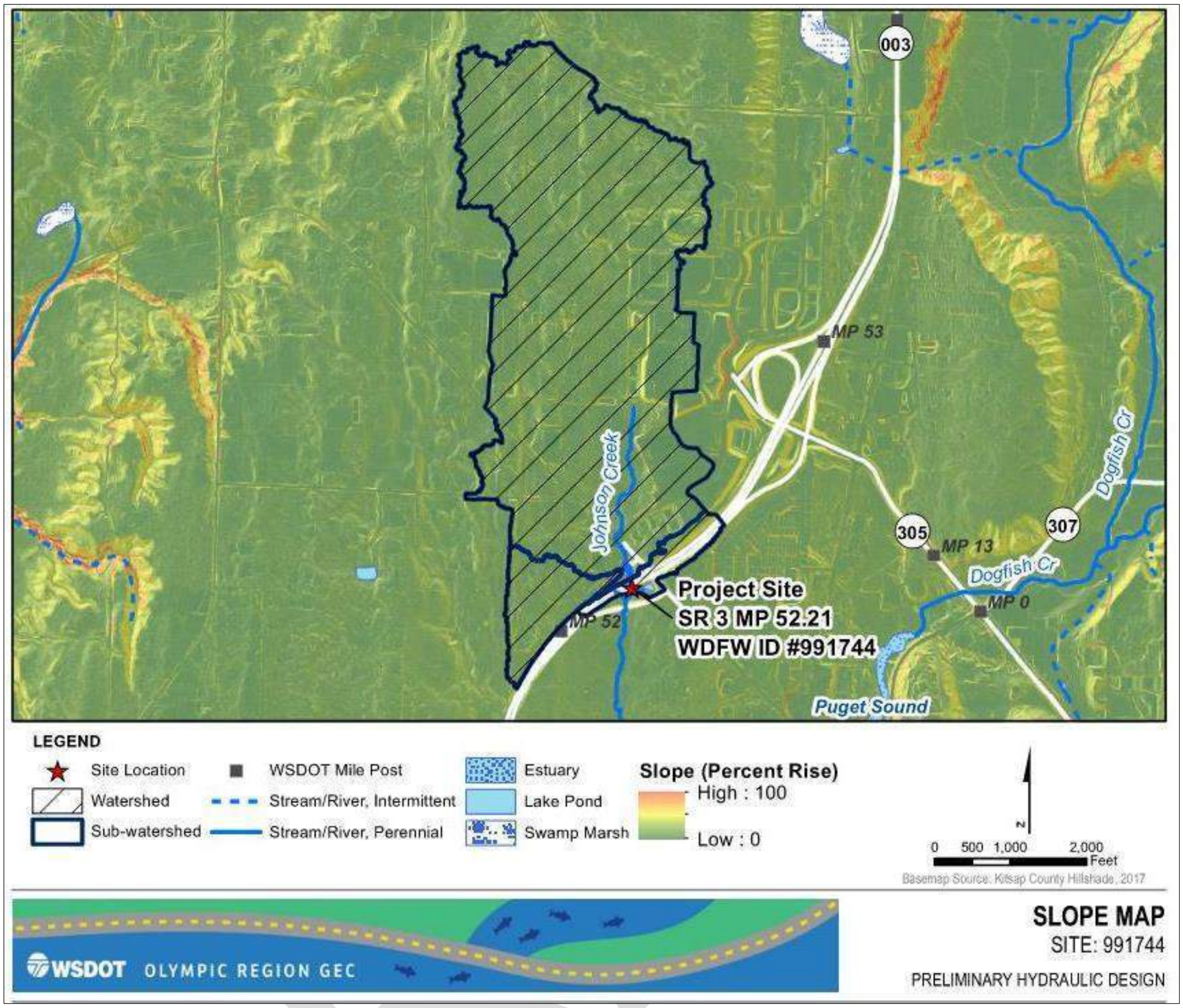


Figure 3: Slope map

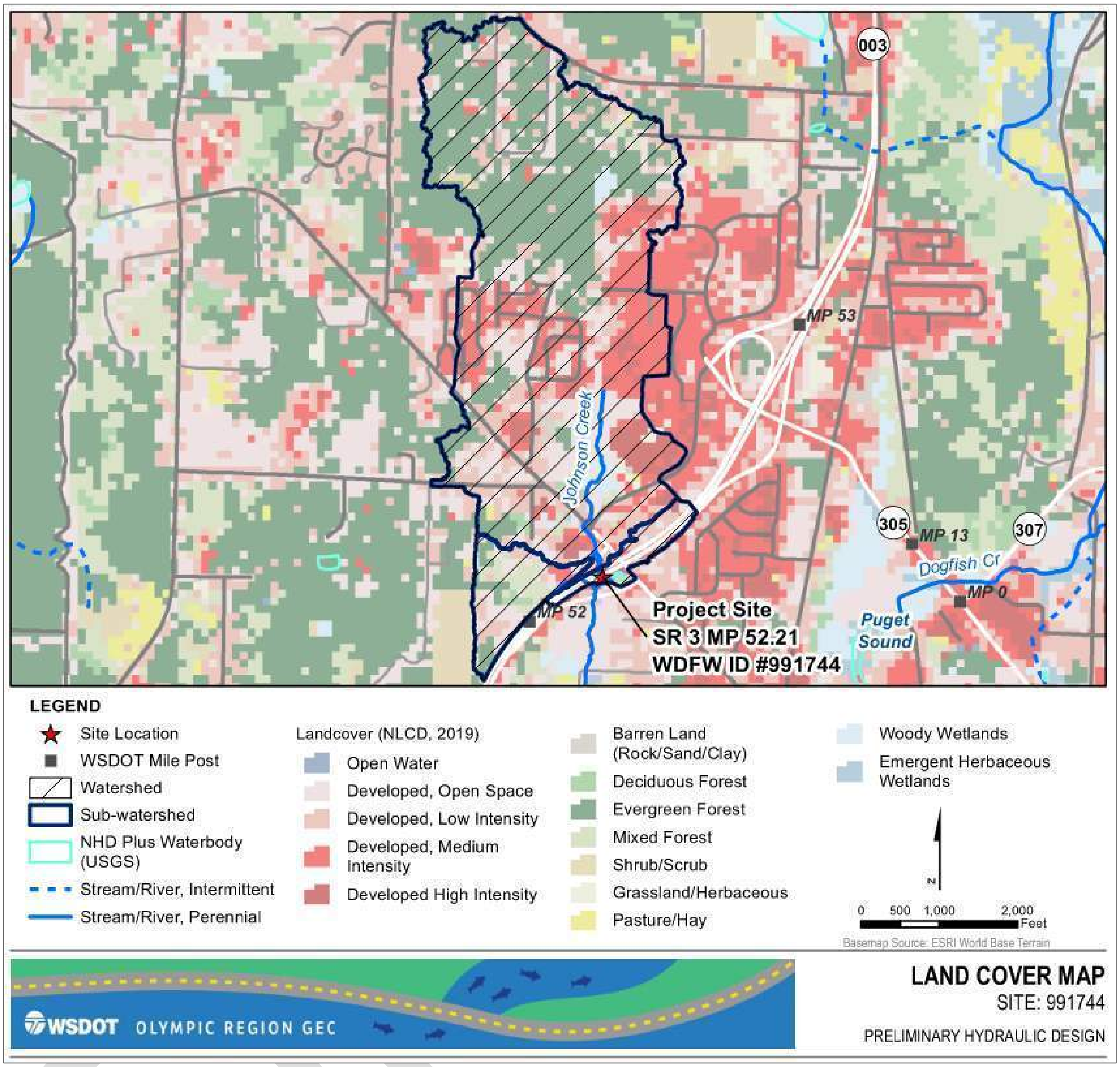


Figure 4: Land cover map

2.3 Geology and Soils

Geology in the basin is dominated by the Pleistocene continental glacial drift lithologic unit with a small area of Pleistocene continental glacial till in the southwest portion of the basin (Figure 5). The geologic unit associated with this lithology is Vashon ice-contact deposit (Haugerud 2009). This unit is often a loose, poorly sorted mixture of silty to sandy pebble gravel to cobble, typically deposited in stagnant ice environments. This unit is typically friable, which causes it to be permeable. Additional geomorphic mapping (Haugerud 2009) shows that the lower portion of the watershed is mapped as fluted glaciated surface and the upper portion mapped as pockmarked glaciated surface. The glacial flute trends north-south, reflecting the direction of the Cordilleran ice sheet, and is roughly subparallel to other adjacent glacial flutes. Johnson Creek follows the axis of the flute to where it drains to Liberty Bay. This topographic setting drives the alignment and profile of the channel. While there is abundant source material in the basin, the low to moderate gradient of the watershed tends to limit the movement of hillslope-derived sediment to the stream channel. The low relief fluted surface has gentle slopes (Figure 3) and exhibits no sign of mass-wasting in LiDAR-derived hillshade (Kitsap County 2017; Figure 6).

Soils in the Johnson Creek watershed are primarily Poulsbo gravelly sandy loam, a moderately well-drained soil that is generally formed from basal till (Figure 7; Natural Resources Conservation Service, U. S. Department of Agriculture [NRCS USDA] 2021). The hydrologic soil group ranges from B (moderately low runoff potential) to D (high runoff potential). In the upper portion of the watershed, Poulsbo-Ragnar complex and Sinclair very gravelly sandy loam soils are also present. These soil types are also described as well drained to moderately well drained and derived from basal till. Runoff potential in these soil types is variable, ranging from A (lowest runoff potential) to D (highest runoff potential), dependent on the presence of ash. Soil types and the underlying geology, along with land use and cover, were used to develop a hydrologic model of the basin, discussed in Section 3. Additional geotechnical data to evaluate lateral migration and long-term degradation are not currently available for this crossing.

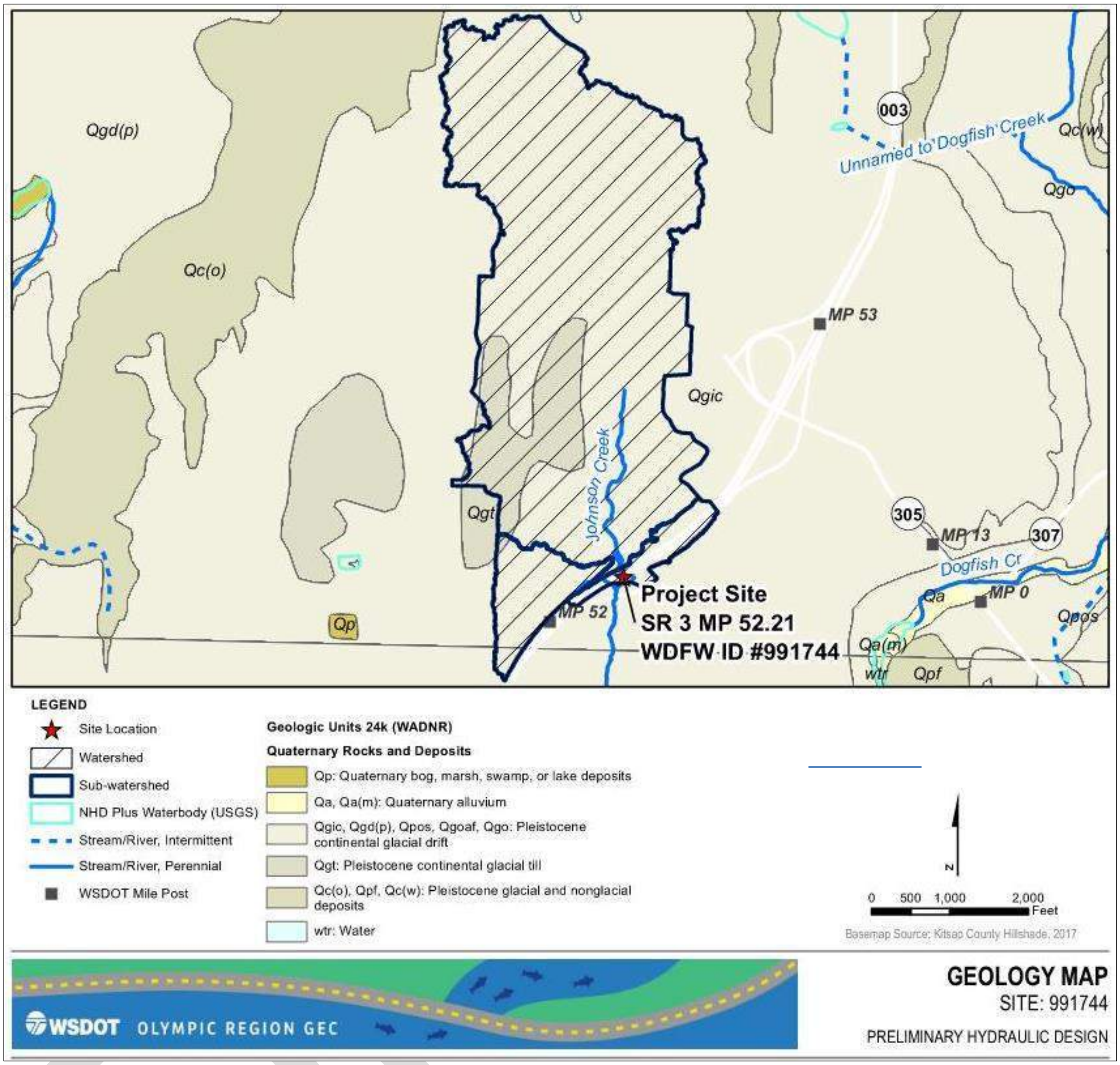


Figure 5: Geology map

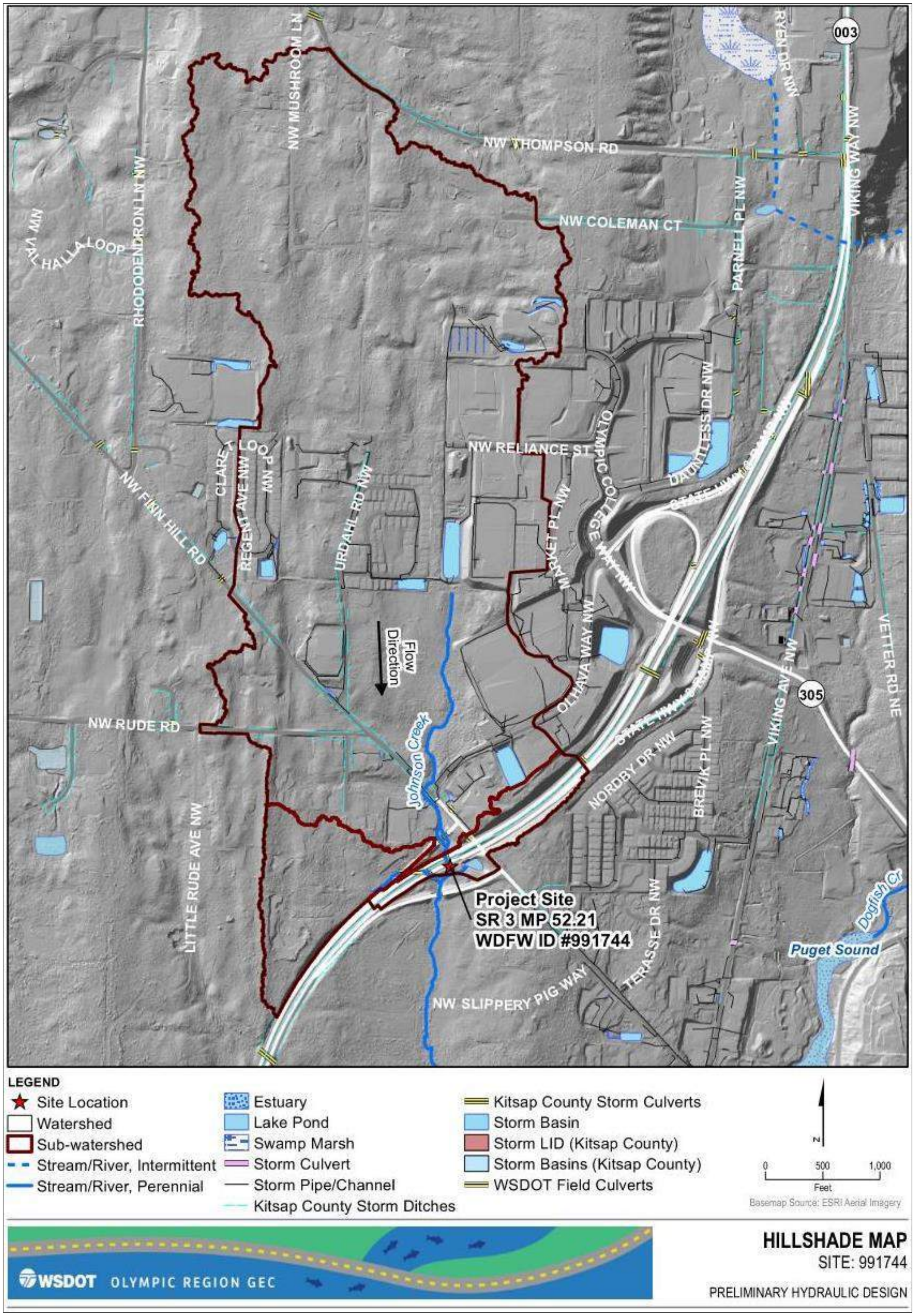


Figure 6: Hillshade map

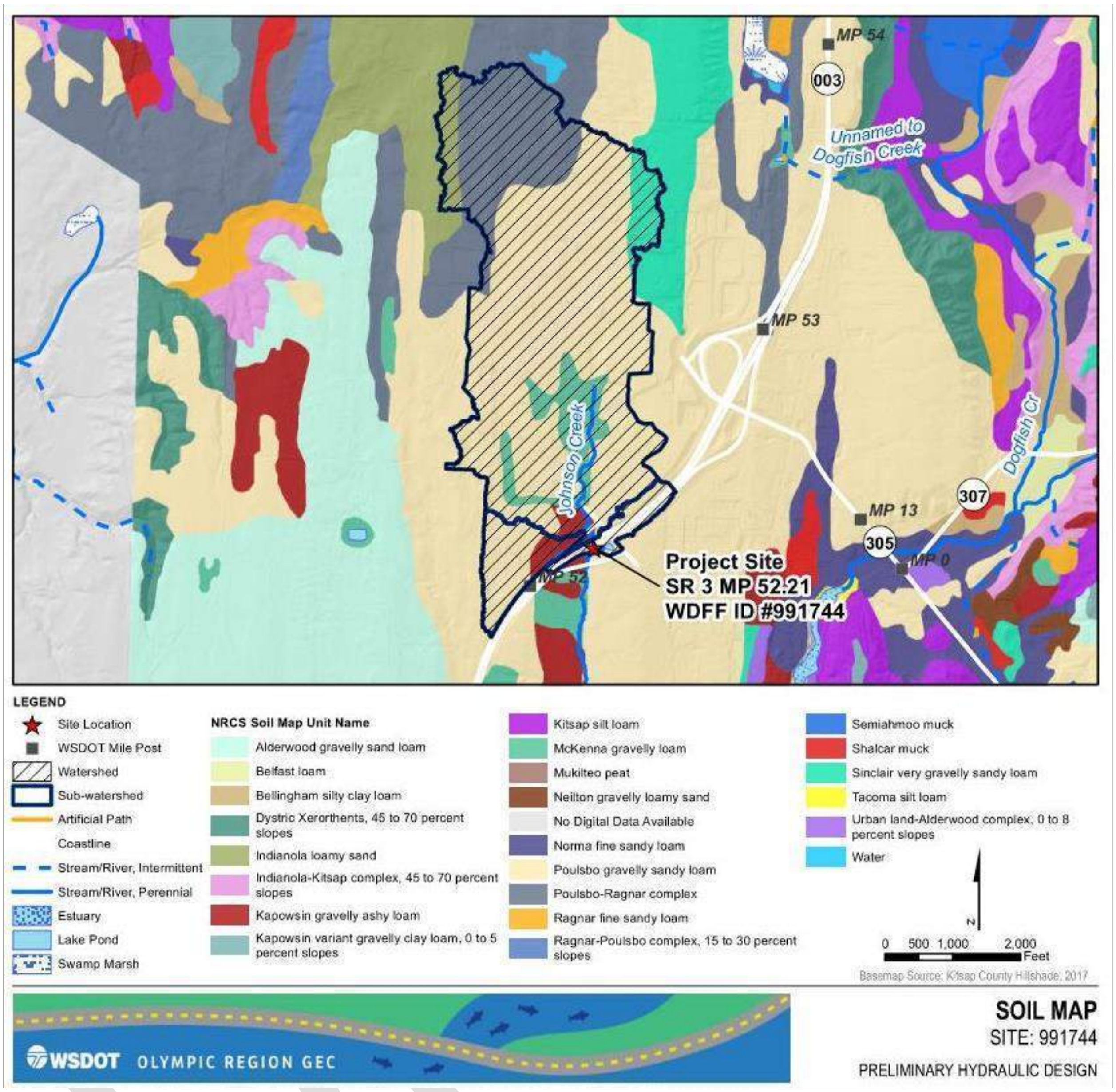


Figure 7: Soils map

2.4 Fish Presence in the Project Area

Jacobs staff reviewed multiple publicly available information sources regarding historical and current fisheries resources and distribution within the project area, including the following:

- WDFW Fish Passage and Diversion Screening Inventory database (n.d.-b), which includes a compilation of barrier and habitat assessment reports
- WDFW Fish Passage and Diversion Screening Inventory database, Level A Culvert Assessment Report for Johnson Creek (1999).
- Statewide Washington Integrated Fish Distribution database (Northwest Indian Fisheries Commission [NWIFC] n.d.)
- Ecology Watershed Restoration and Enhancement Draft Plan, WRIA 15 Kitsap Watershed (2021)
- National Marine Fisheries Service (NMFS) Essential Fish Habitat Mapper (n.d.)
- WDFW APPS Hydraulic Project Approval database search by Section/Township/Range (n.d.-c; no projects within the vicinity)
- Washington State Recreation and Conservation Office project database (n.d.; no projects within the vicinity)
- Site observations by preliminary hydraulic design (PHD) project fisheries biologist on November 30, 2021.

Jacobs representatives, including a fisheries biologist, conducted a site visit on November 30, 2021, to document the existing conditions of the channel upstream and downstream of the crossing.

Johnson Creek has the potential to support migration, spawning, and rearing of native resident and anadromous fish species, including coho salmon, steelhead trout, and cutthroat trout (WDFW 1999). Utilization of Johnson Creek by Chinook salmon and bull trout is unlikely. Chinook and bull trout are not documented to occur in Main Fork Johnson Creek or any of its tributaries (NWIFC n.d.). Similarly, utilization by chum salmon is unlikely given that the upstream and downstream reach have a gradient of 3.1 to 3.4 percent, above the low-gradient streams preferred by chum (typically under 3 percent). Streams with a channel width greater than 2 feet and a contributing basin larger than 50 acres in Western Washington are presumed to have fish use (Washington Administrative Code [WAC] 22-16-131).

Streams with existing or historic fish use within this region are mapped as Essential Fish Habitat for Pacific salmon under the Magnuson-Stevens Fishery Conservation and Management Act for Chinook, pink, and coho salmon; therefore, Johnson Creek is identified as Essential Fish Habitat for salmon. Johnson Creek is not listed as designated critical habitat for aquatic species under the federal Endangered Species Act (ESA). Section 2.6.3 discusses fish habitat quality in greater detail, including fish utilization by life stages. Table 2 summarizes aquatic species documented to occur within the project area based on this data review.

Table 2: Native fish species potentially present within the project area

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Puget Sound Steelhead (*Oncorhynchus mykiss*)	Modeled- Gradient Accessible Potential	SWIFD Web App WDFW Fish Passage Report	Threatened, NMFS
Coho Salmon (*O. kisutch*)	Modeled- Gradient Accessible Potential	SWIFD Web App WDFW Fish Passage Report	Not Listed
Cutthroat Trout (Sea Run) (*O. clarkii clarkia*)	Modeled- Gradient Accessible Potential	SWIFD Web App WDFW Fish Passage Report	Not Listed
Cutthroat Trout (Resident) (*O. clarkii clarkia*)	Modeled- Gradient Accessible Potential	SWIFD Web App WDFW Fish Passage Report	Not Listed

Sources: NWIFC n.d.; WDFW 1999.

2.5 Wildlife Connectivity

The 1-mile-long segment that Johnson Creek falls in is not ranked for Ecological Stewardship and is a low priority for Wildlife-related Safety by WSDOT HQ ESO. Adjacent segments to the north and south ranked medium. A wildlife connectivity memorandum will not be provided at this site and additional width or height has not been recommended by WSDOT HQ ESO for wildlife connectivity purposes. This crossing could be considered for wildlife connectivity due to the deep roadway fill.

2.6 Site Assessment

2.6.1 Data Collection

On November 30, 2021, Jacobs staff investigated approximately 200 feet upstream of the culvert inlet (just upstream of the SR 3 on-ramp) and 300 feet downstream of the culvert outlet (just downstream of the SR 3 off-ramp). During this site visit, a reference reach was identified between the on-ramp and the culvert inlet (Figure 8). Two pebble counts (PC 3 and PC 4) and two bankfull width (BFW) measurements (BFW 6 and BFW 8) were made in the reference reach. Seven additional BFW measurements (BFW 1 through BFW 5, BFW 7, and BFW 9) were made on the channel and two additional pebble counts (PC 1 and PC 2) were also made during this site visit. Figure 2 and Figure 8 show a bifurcation in the channel. This bifurcation is assumed to be a split that occurs upstream of the on-ramp crossing, but it was not observed during the site visit. The confluence of the two threads occurs in the reach between the on-ramp crossing and the SR 3 crossing. The smaller of the two threads daylights through the on-ramp embankment through an 18-inch CMP. The BFW 7 measurement was made on the smaller of the two threads for comparison to the larger thread, and comparison to the channel downstream of the confluence.

The reference reach and BFW concurrence site visit with WDFW and the Tribes occurred on February 15, 2022. The consensus of the group was that a BFW of 7.5 feet was acceptable for the proposed design. The group also agreed that the downstream pebble counts would be used in the design due to large fraction of fine materials in the upstream pebble counts. Further detail on sediment is given in Section 2.7.3 and BFW measurements are summarized in Section 2.7.2. Field reports of the November 30 and February 15 site visits are provided in Appendix B.

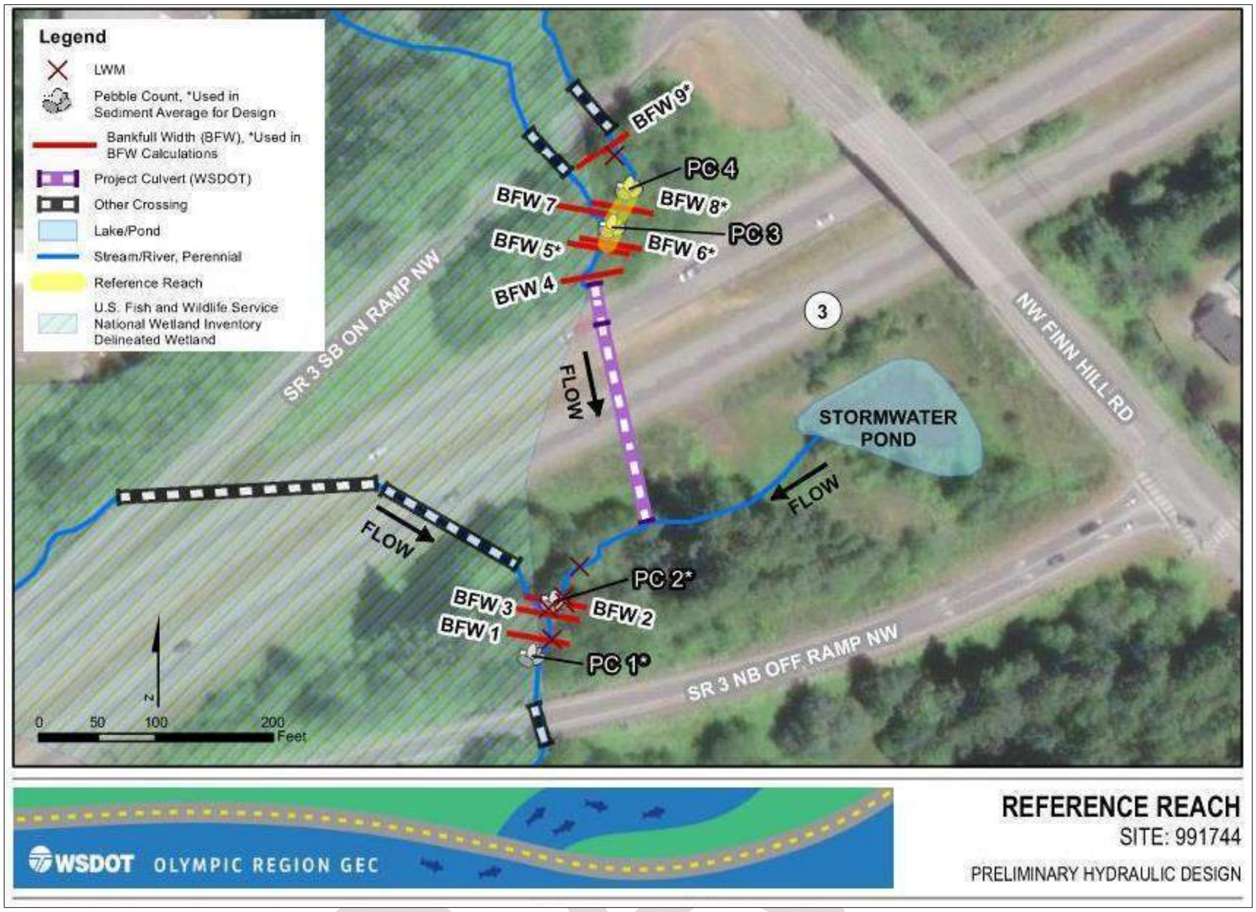


Figure 8: Reference reach, bankfull width, and pebble count locations

2.6.2 Existing Conditions

The existing crossing consists of a 36-inch-diameter, 211-foot-long CMP that runs north to south at a skew to the highway with an overall gradient of 3.4 percent. The inlet and outlet are shown on Figure 9 and Figure 10, respectively. There is approximately 7 to 10 vertical feet between the culvert crown and the road surface. As-builts for the Finn Hill Interchange (WSDOT 1993b) and Luoto Road Interchange to SR 305 Interchange (WSDOT 1993a), which are near the vicinity of the existing SR 3 culvert, were obtained from WSDOT HQ. The as-builts showed that the existing 36-inch crossing was placed at 2.96 percent. There were no obvious signs of maintenance.

The surrounding Johnson Creek reaches are highly anthropogenic. Approximately 130 feet upstream of the SR 3 crossing inlet, at the SR 3 on-ramp, is an approximately 8.5-foot-high by 13.5-foot-wide structural plate steel arch culvert (WDFW ID 996805). This on-ramp arch culvert is 100 percent passable per the 2021 WDFW Level A Culvert Assessment Report (WDFW 2021a). Approximately 160 feet downstream of the SR 3 outlet, at the SR 3 off-ramp, is an approximately 8-foot-high by 13.5-foot-wide structural plate steel arch culvert (WDFW ID 996807). This off-ramp arch culvert is 100 percent passable per the 2021 WDFW Level A Culvert Assessment Report (WDFW 2021b). Immediately downstream of the SR 3 culvert outlet, a small channel draining a stormwater pond enters the channel. The stormwater pond is located about 80 feet to the east of the culvert outlet. The configuration of these water sources is depicted on Figure 11.

Between the upstream SR 3 on-ramp and the SR 3 crossing, the channel has limited (<1.1) sinuosity. The only significant meander bend is just upstream of the SR 3 culvert inlet. This bend has an approximate radius of curvature of 12 to 15 feet. This upstream reach (Figure 12) is characterized by mapped wetlands (Figure 8); an active, well-vegetated floodplain of deciduous trees; and an overall slope of roughly 3 percent. The channel is narrow and deep, with low banks and minimal large woody material (LWM) in the channel. The narrow and deep channel morphology in the upstream reach provides cover for fish, but the lack of LWM limits additional habitat development.

Between the SR 3 outlet and the SR 3 off-ramp, the reach also has mapped wetlands, but the floodplain is composed of coniferous trees and some LWM in the downstream channel (Figure 13). The channel alignment has low sinuosity (<1.1), is entrenched relative to the floodplain, and has an overall slope of 2.5 percent. At the culvert outlet, the channel makes a significant meander bend (Rc = 70-100 feet), resulting in an undercut of the left bank (looking downstream) and a small scour pool. This pool is 2 to 3 feet long and about 1-foot deep. In the downstream reach, some LWM provides habitat, but the lack of floodplain access concentrates in-channel flows and limits use by some age classes. Additionally, as noted in Section 2.1, the culvert crossing is considered a slope barrier due to the lack of embedment, and slope greater than 1 percent and the lack of streambed material in the crossing means a lack of habitat. Detailed information on channel geometry is given in Section 2.7.2. Information on existing riparian vegetation conditions, LWM, and canopy cover is given in Section 2.6.4.

Figure 9: SR 3 culvert inlet

Figure 10: SR 3 culvert outlet

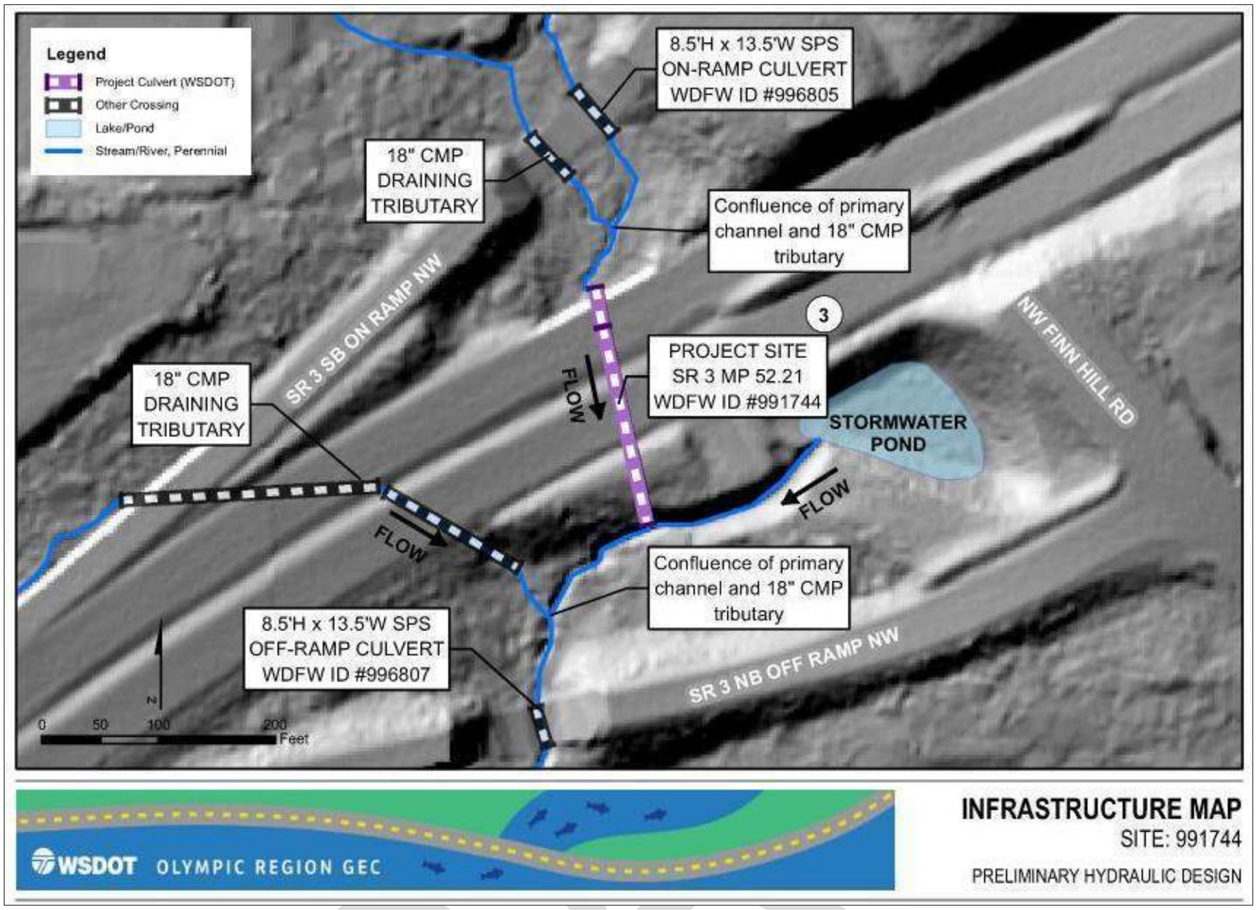


Figure 11: Infrastructure map

Figure 12: Upstream reach (looking downstream)

Figure 13: Downstream reach (looking downstream)

2.6.3 Fish Habitat Character and Quality

The National Hydrography Dataset identifies Johnson Creek as a perennially flowing stream (USGS 2019). Field indications support the determination of a perennially flowing waterbody, including a well-defined channel, clean sand and gravel substrate, and lack of vegetation below ordinary high water. Prior to the construction of SR 3, Johnson Creek in this location flowed through an unconfined, low-gradient, forested wetland valley (U.S. Fish and Wildlife Service n.d.). The installation of SR 3, including its widening and construction of the on-ramp and off-ramp in the early 1990s, have limited normative fluvial and riparian processes in both upstream and downstream reaches, though wetland conditions persist throughout the site, based on the field survey conducted by a Jacobs biologist.

Instream habitat conditions in the upstream reach of Johnson Creek consist of a low-energy glide morphology with limited sinuosity. The channel is located within an unconfined valley with a floodplain averaging more than five times the width of ordinary high water, consisting of a broad and flat deciduous forested floodplain with evidence of long-term beaver influence (Figure 14), as evidenced by deep, organic material and silt within the substrate and throughout the adjacent floodplain. Pools are shallow and infrequent, consisting of undercut banks created by living riparian tree roots and racked material consisting of smaller deciduous branches and leaves, as well as a large and broad pool immediately upstream of an older beaver dam. The entirety of the upstream reach is mapped freshwater palustrine forested/temporary flooded (U.S. Fish and Wildlife Service n.d.).

The presence of wetland vegetation was observed throughout the floodplain. Floodplain connectivity is unobstructed within this reach and the aggraded channel bed may allow for foraging by juvenile salmonids (resident and anadromous) throughout the floodplain during bank-topping flows. Substrate in the upstream reach consists primarily of a deep layer of organic material (verified by difficulty traversing the area without sinking) and silt and fine sand, with areas of small gravels limited to the areas immediately adjacent to the existing culverts. The size of the stream, substrate, and depth of water within the upstream reach is suitable for rearing and migration and is excellent for foraging opportunities for juvenile salmonids of all species during bank-topping flows, particularly for juvenile cutthroat, steelhead, and coho salmon, which have longer freshwater rearing cycles. Spawning habitat within the upstream reach is limited due to the dominance of deep silt and organic material within the substrate; however, smaller pockets of gravel associated with the existing crossings may be utilized by spawning cutthroat trout.

Instream habitat conditions in the downstream reach consist of a low-gradient, riffle-glide morphology within a relatively confined valley. Normative fluvial processes are also limited in the downstream reach, due in part to confinement of the channel between SR 3 and the SR 3 off-ramp. Although both reaches have a sinuosity of less than 1.1, the downstream channel is slightly more sinuous in this reach as compared to the upstream reach, dividing at one point into two threads. The channel shows signs of downcutting, based on undercut and exposed banks as well as exposed tree roots on the banks. Pools are intermittent and are limited to undercut banks with lateral pools (Figure 15) and shallow scour pools associated with infrequent LWM from legacy material and more recent smaller material. Floodplain connectivity is limited to absent given the confined nature of the channel, due in part to steep downcutting. Instream substrate appears mobile and not embedded, consisting of small- to medium-sized gravels, which are clean and free from algal growth. The size of the stream, substrate, and depth of water within the downstream reach is suitable for spawning, migration, and rearing of resident and anadromous fish species present in the system (discussed in Section 2.4).

Figure 14: Upstream reach, facing downstream (note the beaver dam; a large, broad pool upstream of the dam; and deposits of deep, organic material in floodplain).

Figure 15: Downstream reach (note the lateral pool associated with an undercut bank and the living riparian tree roots).

2.6.4 *Riparian Conditions, Large Wood, and Other Habitat Features*

Riparian vegetation within the upstream reach consists of early-seral floodplain wetland vegetation, typical of a floodplain influenced by beaver activity over an extended period of time. Evidence of persistent and long-term ponding, likely due to beaver activity, was noted as a deep layer of organic material within the substrate and surrounding floodplain, gnawed stumps, and at least one channel-spanning beaver dam, though it did not appear to have been recently maintained at the time of survey. The canopy (Figure 16) is dominated by young Western red alder (*Alnus rubra*) with a dense understory of salmonberry (*Rubus spectabilis*) and with lesser occurrence of Osoberry (*Oemleria cerasiformis*) and wetland sedges and forbs. Floodplain soils consist of deep, organic material, commonly found in relic flooded floodplains influenced by beavers. Large, coniferous LWM is absent, possibly due to past removal and/or logging activities, and instream material is limited to small, deciduous material and relic beaver dams that have racked branches and other smaller organic matter. Deciduous wood plays an important role in providing instream nutrient recruitment but has a much faster decay rate compared to coniferous LWM, limiting its role in forming longer-term channel complexity features, including persistent pool formation.

Riparian vegetation within the downstream reach (Figure 17) consists predominantly of a narrow band of mature, late-successional coniferous and deciduous riparian community species dominated by Western red cedar (*Thuja plicata*) with Western red alder toward the edges of the stand. Understory species consists of sword fern (*Polystichum munitum*), ivy (Hedera helix), and salmonberry, where the canopy is more open. Standing conifer snags are present and are heavily used by woodpeckers and other wildlife. Some coniferous LWM is present within the channel, though the majority is legacy material (LWM present in streams prior to widespread logging in the early twentieth century) of varying degrees of decay. The removal of the majority of mature conifers across the West removed a generation of coniferous LWM recruitment potential.

Mature cedars within the downstream reach likely regenerated within the last 100 years and are of similar age, consistent with early twentieth-century postindustrial logging regrowth. The expectant life span of these coniferous tree species can exceed several hundred years; therefore, outside of environmental disturbance such as windfall, these stands would not be expected to serve as significant LWM recruitment potential due to their relative natural longevity. Environmental disturbance, such as periodic windfall and disease, would be the likely pathways for more significant LWM recruitment than age-induced decay.

The presence of LWM and corresponding pools for salmonid refugia and cover in the upstream reach is estimated to be deficient and is moderately deficient in the downstream reach, as compared to the target number of key pieces of LWM for Western Washington (WSDOT 2022; Fox and Bolton 2007). No evidence of beaver activity was noted in the downstream reach, but eliminating the existing fish barrier could provide beaver access to the downstream reach.

Figure 16: Upstream reach (note the canopy dominated by young alders and the presence of beaver-gnawed stumps.

Figure 17: Downstream reach (note a closed canopy of Western red cedars, standing snags, and an open understory).

2.7 Geomorphology

Geomorphic information provided for this site includes selection of a reference reach, the geometry and cross sections of the channel, and the vertical and lateral stability of the Johnson Creek channel.

2.7.1 Reference Reach Selection

To help inform new channel design, a reference reach was identified during the site visit on November 30, 2021, and agreed to by the comanagers on February 15, 2022. The identified reference reach begins approximately 50 feet upstream of the SR 3 crossing and extends another 100 feet upstream, between SR 3 and the SR 3 on-ramp (Figure 8). This reach (Figure 18 and Figure 19) was chosen because it is a self-formed alluvial channel proximal to the crossing, with a similar gradient (3.1 percent) as the crossing (3.4 percent), and with relatively natural vegetation that has developed since SR 3 and the on-ramp were constructed. The reference reach is lacking in LWM, and much of the floodplain is mapped wetland so it is not an ideal reference reach. However, the entire reach between the SR 3 crossing and the on-ramp has active engagement with the floodplain. Two other reference reach locations were considered: a segment downstream of the crossing between SR 3 and the SR 3 off-ramp, and a segment upstream of the SR 3 on-ramp.

The downstream reach has a more mature riparian canopy and the channel through it is incised with near-vertical banks and little floodplain connection. Downstream reaches were typically entrenched (disconnected from the floodplain) and become more entrenched with increasing downstream distance. The lack of floodplain connectivity is typically considered less valuable for fish habitat. The reach upstream of the on-ramp was similar to the reference reach but was not selected due to its very flat gradient and the presence of wetlands.

Figure 18: Reference reach, looking downstream

Figure 19: Reference reach, looking upstream

2.7.2 Channel Geometry

The existing channel and floodplain have marked differences from upstream to downstream of the crossing (Figure 20). Upstream of the SR 3 crossing, the floodplain is composed almost entirely of deciduous trees and shrubs. Consequently, little LWM was observed in the channel. Channel sinuosity is limited (<1.1) but the channel is unconfined within the floodplain. The floodplain width is limited to 100 to 200 feet between the road embankments of SR 3, the on-ramp, and NW Finn Hill Road. The upstream channel and floodplain are well connected, in part because of backwater effects at the SR 3 crossing.

Downstream of the SR 3 crossing, the floodplain is coniferous with a swordfern understory; however, the channel is entrenched with little access to the floodplain (Figure 21). The cause of the entrenchment is speculative, but further downstream the degree of entrenchment and depth of incision increases. These observations point to a headcut migrating upstream. The floodplain is wider (approximately 500 feet), but, similar to the upstream reach, the floodplain is confined by SR 3, the off-ramp, and NW Finn Hill Road. Channel sinuosity is similar to upstream (<1.1).

The channel geometry was observed in the field and assessed by topographic survey. As previously mentioned in Section 2.6.3, the observed bedforms consist of riffles, glides, and pools. While generally lacking in wood upstream, forced pools are formed by accumulated organic debris and range from 5 to 9 feet wide and 1 to 2 feet deep (Figure 22). Runs are narrow (2 to 3 feet wide) and deep (up to 3 feet). Riffles range from 0.3- to 1-foot deep. Banks are generally low, especially in the forced pools, but are approximately 1-foot high and near vertical in the runs. In the upstream reach, banks are composed of fine, silty, cohesive materials. The near-vertical banks create a narrow and deep channel, with a width-to-depth ratio of roughly 3 to 5. As mentioned previously, the slope of the reference reach is roughly 3.1 percent, which is similar to the slope of the existing crossing (3.4 percent); additional information regarding slope ratio is presented in Section 4.1.3. The selected design slope should facilitate uniform flow conditions without sharp transitions in energy grade slope. Consideration of the minimum hydraulic width is also driven by the selection of design slope.

The downstream channel has a similar distribution of riffle-pool channel features, though with fewer pools. Channel widths and depths tend to be higher, commonly near 9 and 3 feet, respectively. Some LWM was observed in the channel but due to the entrenched nature of the channel, wood tends to span the channel. Banks are taller in the downstream reach (up to 3 feet), fine grained and cohesive, and near vertical. The entrenched nature of the channel has led to some bank undercutting and subsequent slight channel widening; overall, the channel shape tends to be narrow and deep (Figure 23), resulting in a width-to-depth ratio of 4 to 7. The upstream channel is best classified as Stage 1 of the Cluer and Thorne (2013) stream evolution model (Figure 24), with a somewhat sinuous, single-thread channel and generally good floodplain connectivity; the downstream channel is closer to Stage 2 (channelized) and exhibiting some characteristics of Stage 3, such as abandonment of the floodplain.

Two BFW measurements were taken in the reference reach, and five others were taken in other locations in the vicinity including three in the downstream reach and one on the bifurcated channel (smaller of the two threads) that drains to the reference reach). BFW was measured at the locations shown on Figure 8 and summarized in Table 3. BFWs measured 3 to 9 feet in the upstream reference reach and 7 to 9 feet in the downstream reach. The BFWs used for the average, 5.6 feet, noted in Table 3 are used as they appeared to not be influenced by surrounding infrastructure. However, during the concurrence site visit with the comanagers, a BFW of 7.5 feet was agreed to by the attendees. A range of channel locations were selected, but a BFW of 7.5 feet seemed to best represent the median.

Figure 20: Comparison of upstream and downstream channel conditions.

Figure 21: Typical downstream channel conditions: entrenched channel and steep, vertical banks.

Figure 22: Typical forced pool in upstream channel reach (looking upstream).

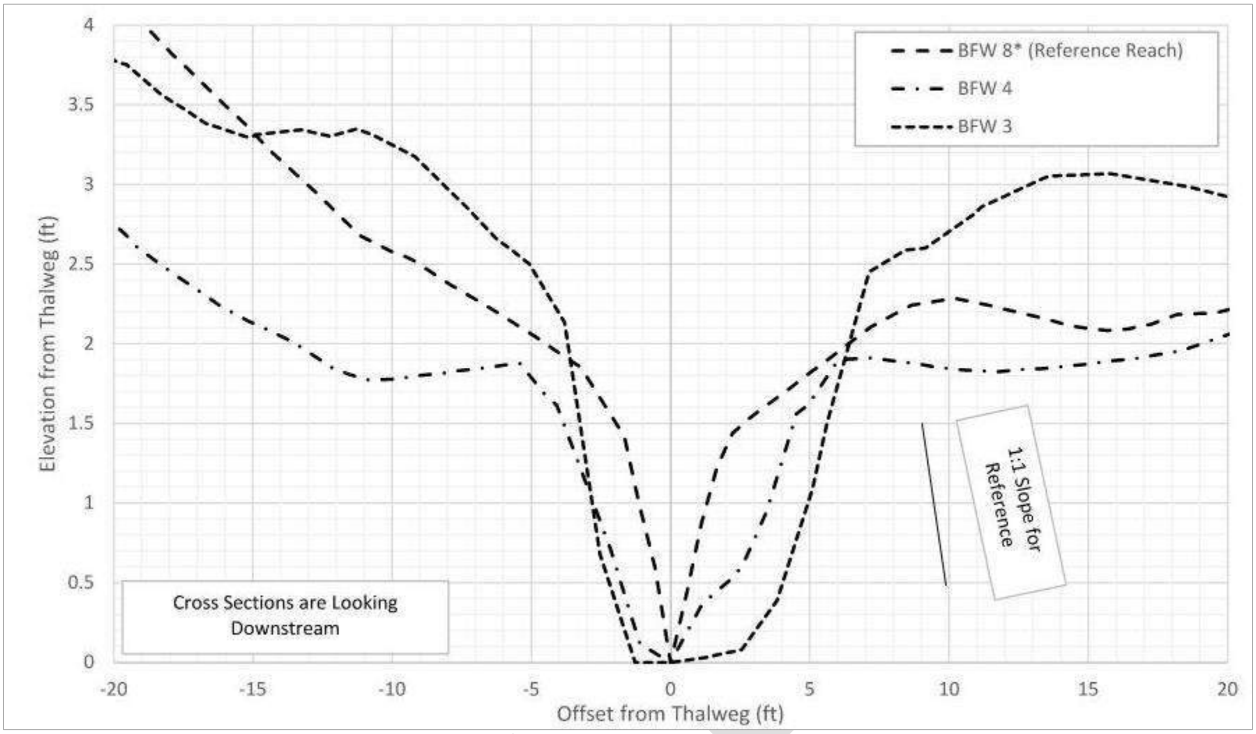


Figure 23: Existing cross section examples

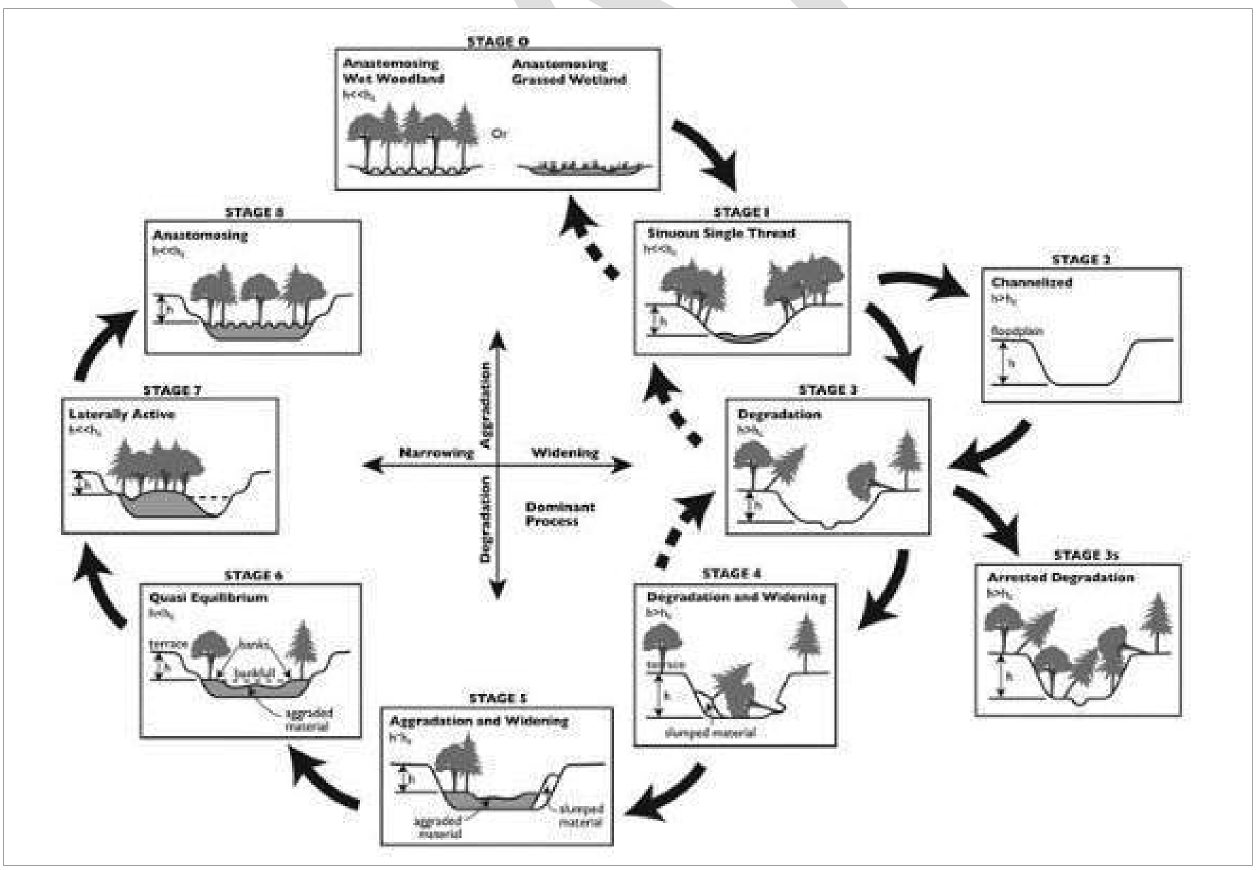


Figure 24: Stream evolution model (Cluer and Thorne 2013)

Table 3: Bankfull width measurements

BFW number	Width (ft)	Included in design average?	Location measured	Concurrence notes
1	8.8	No	STA E10+89	Comanager concurred on 02/15/2022
2	8.9	No	STA E11+27	Comanager concurred on 02/15/2022
3	7.0	No	STA E11+12	Comanager concurred on 02/15/2022
4	7.0	No	STA E14+30	Comanager concurred on 02/15/2022
5	4.5	Yes	STA E14+64	Comanager concurred on 02/15/2022
6	3.0	Yes	STA E14+68	Comanager removed on 02/15/2022
7	3.0	No	STA E14+85 (on Trib)	Comanager concurred on 02/15/2022
8	6.0	Yes	STA E14+98	Comanager added on 02/15/2022
9	9.0	Yes	STA E15+58	Comanager concurred on 02/15/2022
Design average	**5.6**	N/A	N/A	Comanager decided a BFW of 7.5 should be used for design on 02/15/2022

2.7.2.1 Floodplain Utilization Ratio

The floodplain utilization ratio (FUR) is defined as the flood-prone width (FPW) divided by the BFW. The FPW is defined as the inundated width at the 100-year mean recurrence interval (MRI) event, which was extracted from the U.S. Bureau of Reclamation's Sedimentation and River Hydraulics – Two Dimension (SRH-2D) Version 3.3.1 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (2020). The BFW was measured in the field and is discussed in Section 2.7.2. Under existing conditions, the reach upstream of the SR 3 culvert is impacted by backwater at the 100-year MRI. A natural-conditions model with an artificially widening the SR 3 culvert from a 36-inch-diameter circular culvert to a 40- by 20-foot concrete box culvert was created to remove these impacts, discussed in further detail in Section 5.3, and 100-year MRI results from this model were used to determine the FPW upstream of SR 3.

The FUR was calculated at all nine of the field-measured BFW locations, as shown on Figure 25. Table 4 shows the FPW measurement and the calculated FUR at each location. Upstream of the existing crossing, the highest calculated FUR in the upstream reach was 21.6 and the lowest was 6.0. Downstream of the crossing, the highest FUR calculated was 8.5 and the lowest calculated at 6.5. The overall average FPW equals 57.2 feet with a resulting average FUR for the entire reach of 14.3. BFW 7 was not included in the average FUR calculation as it is located on the bifurcated channel thread, not the main channel. BFW 9 was also not included in the average FUR calculation as it is within the influence of the on-ramp culvert outlet. All of the FUR values included in the average calculations are above 3.0, indicating that the channel is unconfined. This is further supported by hydraulic modeling as the 2-year event consistently overtops the channel and spreads out across the floodplain valley. This is particularly prevalent in the upstream reach, where the channel is narrow and the floodplain is actively engaged.

Table 4: FUR determination

Station	FPW (ft)	BFW (ft)	FUR	Confined/ unconfined	Included in average FUR determination
BFW 1 (STA E10+89)	57.1	8.8	6.5	Unconfined	Yes
BFW 3 (STA E11+12)	59.5	7.0	8.5	Unconfined	Yes
BFW 2 (STA E11+27)	61.5	8.9	6.9	Unconfined	Yes
BFW 4 (STA E14+30)	51.0	7.0	7.3	Unconfined	Yes
BFW 5 (STA E14+64)	63.1	4.5	14.0	Unconfined	Yes
BFW 6 (STA E14+68)	64.8	3.0	21.6	Unconfined	Yes
BFW 7 (STA E14+85) (On Trib)	59.3	3.0	19.8	Unconfined	Yes (on bifurcated thread)
BFW 8 (STA E14+98)	43.4	6.0	7.2	Unconfined	Yes
BFW 9 (STA E15+58)	54.0	9.0	6.0	Unconfined	Yes
Average	**57.2**	5.6	**14.3**	Unconfined	—

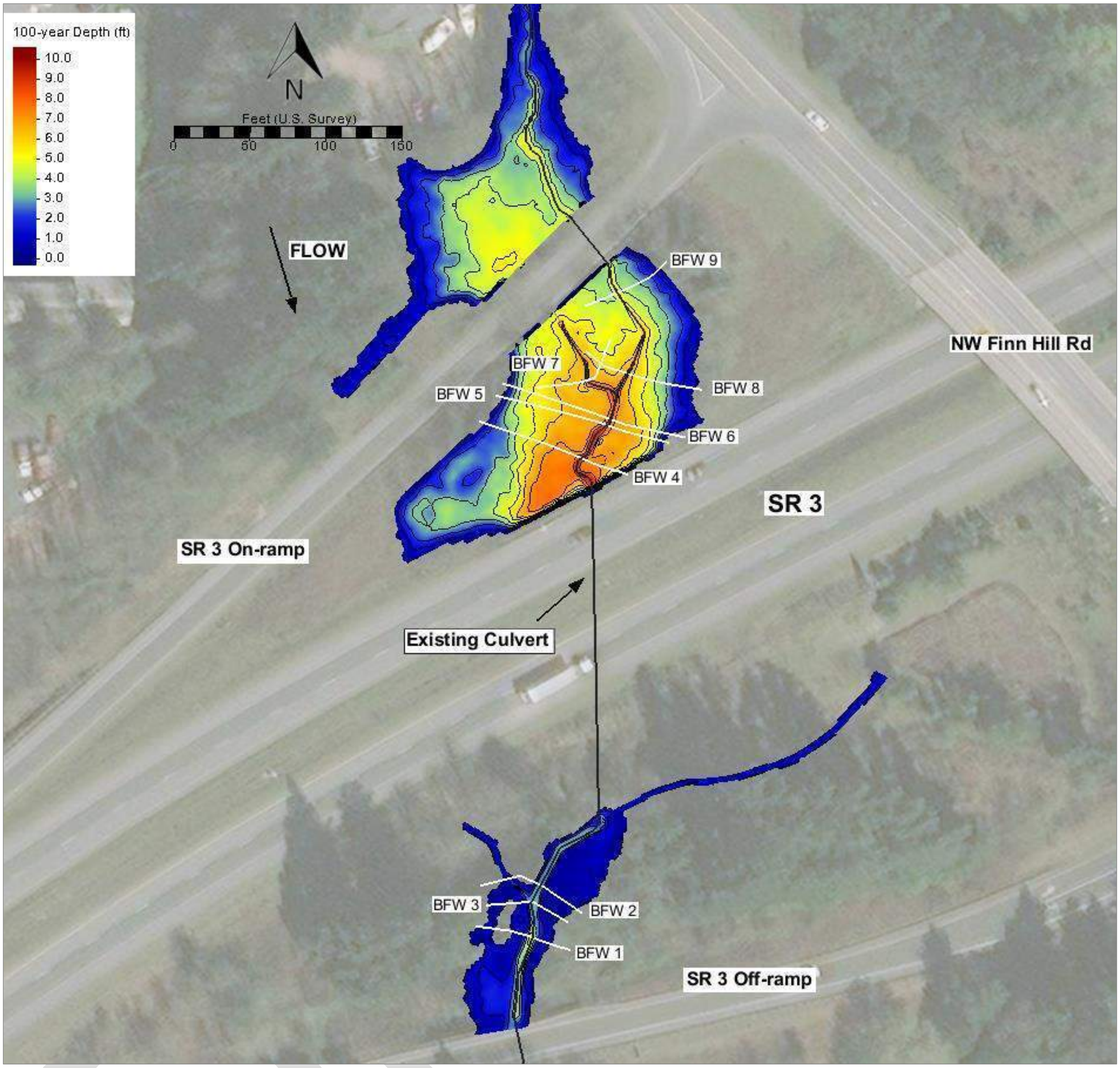


Figure 25: FUR locations

2.7.3 Sediment

The channel bed material upstream and downstream of the crossing was characterized by four Wolman pebble counts: two in the upstream reach and two in the downstream reach. Both upstream pebble counts were collected in the reference reach (Figure 8). Sediments upstream and downstream of the crossing are dominated by small gravels and finer sediments (Figure 26). Upstream sediments are finer than downstream, likely due in part to backwater conditions at the culvert inlet. No boulders were observed, and observed cobbles were assumed to be associated with the stormwater inflow channel and material placed in the on-ramp and off-ramp culverts.

The cumulative grain size distributions and histograms of the pebble counts (Figure 27) show that the upstream pebble counts have a significant mode in silt to very fine sand. For this reason, the comanagers agreed that the downstream pebble counts would be used in the design. The average median grain size for design (D_{50}) is 0.5 inch. A summary of the grain size distributions is provided in Table 5.

Figure 26: Typical upstream bed material (small gravels circled)

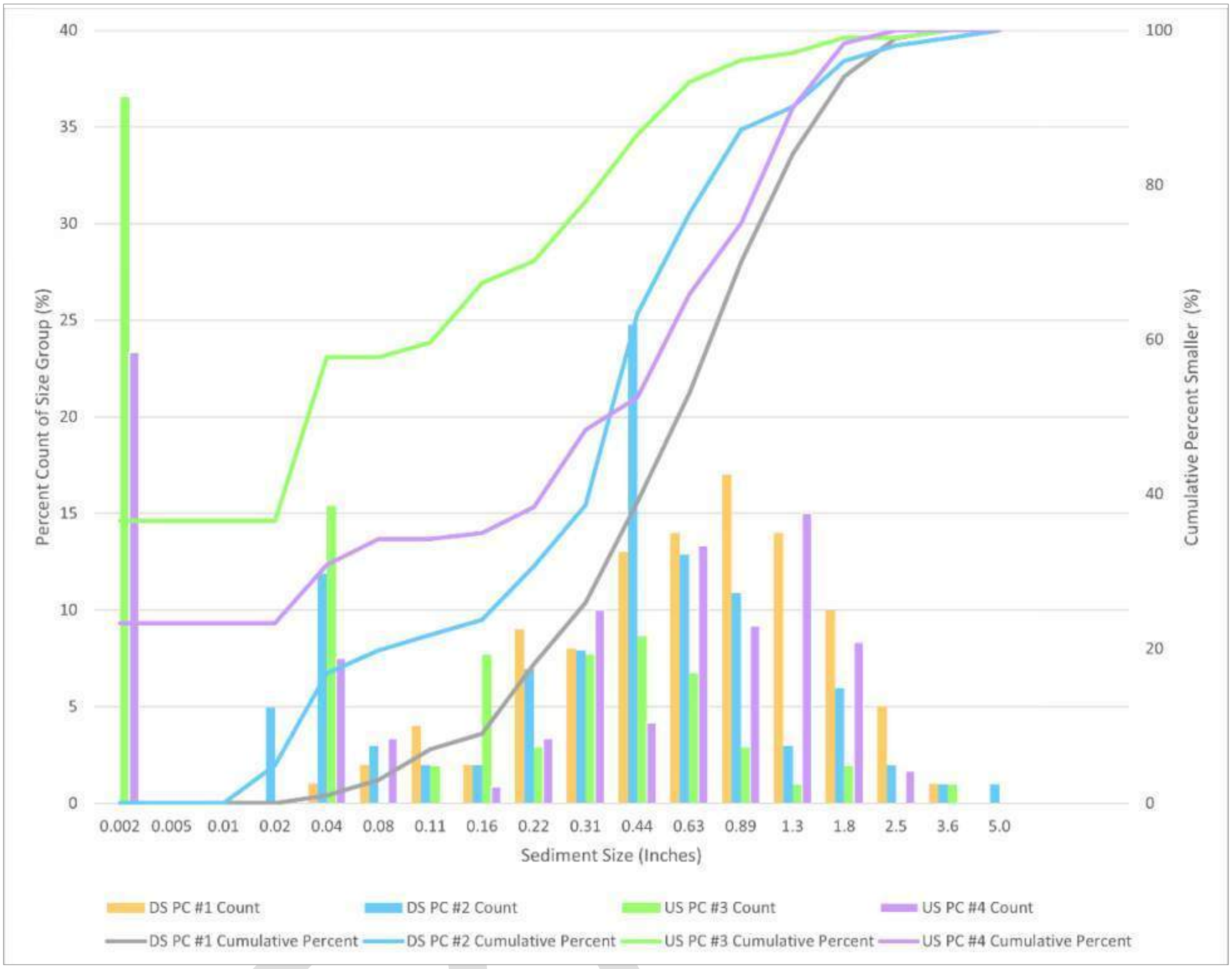


Figure 27: Grain size distributions (cumulative and histogram)

Table 5: Sediment properties near the project crossing

Particle size	Downstream Pebble Count 1 diameter (in)	Downstream Pebble Count 2 diameter (in)	Upstream Pebble Count 3 diameter (in)	Upstream Pebble Count 4 diameter (in)	Average diameter for design (in)
Included in average?	Yes	Yes	No	No	N/A
$\mathbf{D_{16}}$	0.2	0.04	<0.002	<0.002	0.1
$\mathbf{D_{50}}$	0.6	0.4	0.03	0.4	0.5
$\mathbf{D_{84}}$	1.3	0.8	0.4	1.1	1.1
$\mathbf{D_{95}}$	2.5	3.5	0.8	1.6	3.0
$\mathbf{D_{100}}$	3.5	5.0	3.6	2.5	4.3

2.7.4 Vertical Channel Stability

Due to the physiographic setting within the glacial flute, the channel gradient at the watershed scale is remarkably consistent at roughly 2 percent (Figure 28). The WSDOT survey (2021) indicates that the reach-scale gradient (from the on-ramp to the off-ramp) is 3 percent. Despite this consistency in gradient, field observations indicate that the channel downstream has incised and is now entrenched with infrequent connection to the floodplain. This entrenchment increases with increasing downstream distance from the outlet. By contrast, upstream of the outlet the channel is in frequent connection with the floodplain, based on floodplain flow paths and mapped wetlands. The existing structure appears to be holding the grade and preventing headcut migration upstream of the inlet. Downstream incision does not appear to be ongoing, so vertical channel stability appears at least meta-stable. However, upstream vertical channel stability could be compromised, via degradation, if grade control is removed and the hypothesized headcut is able to migrate upstream.

Sediment supply in the basin could be high, given its glacial origins. However, the topographic gradient is low, which limits movement of hillslope-derived sediment to the channel. Consequently, the potential for aggradation is low. Finer sediments have deposited upstream of the inlet but reestablishing the transport of sediment through the crossing is unlikely to modify the entrenched character of the downstream channel.

The controls on aggradation are sediment production and transport. Watershed controls (slope, sediment source) are such that aggradation is unlikely. Degradation is more likely in the upstream reach, up to 2 feet, if the grade control function of the crossing is lost. This degradation would likely compromise the function of mapped wetlands. For this reason, grade control should be retained to prevent degradation.

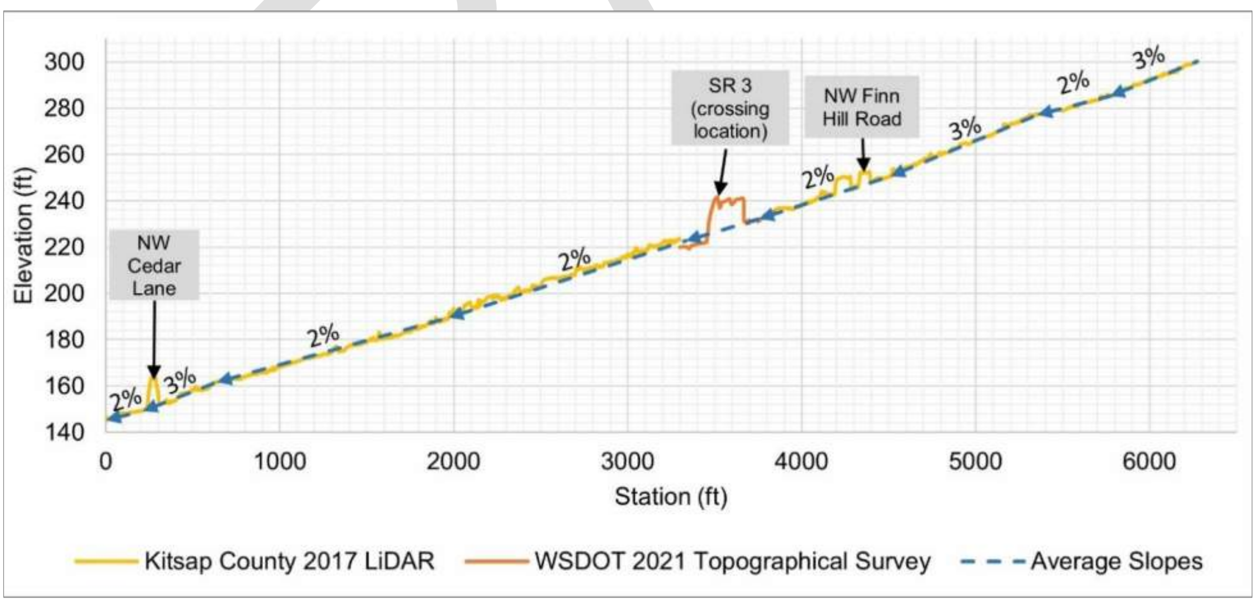


Figure 28: Watershed-scale longitudinal profile

2.7.5 Channel Migration

The basin-scale planform of the channel is straight because the channel is confined within the glacial flute. But at the reach scale, the channel is slightly sinuous as it encounters and flows around obstructions, such as the limited LWM. The upstream reach has a sinuosity of approximately 1.1. The reference reach is actively connected to its floodplain, and floodplain flow paths were observed in the field. The floodplain flow paths appear as subtle, shallow vegetated swales. Channel banks are low but cohesive, so expansion of the floodplain is not expected via meander bend migration. However, much of the area around the channel is mapped as wetland, so there is at least a tight hydrologic connection between the channel and floodplain. Channel change could occur in the context of avulsion (sudden channel movement) if a new obstruction (e.g., fallen tree) blocked flow, forcing a new flow path. The channel’s likelihood to migrate is also a function of hydraulic roughness of the floodplain and obstructions within both the floodplain and channel. Risk of lateral migration is moderate in the upstream reach and low in the downstream reach due to channel entrenchment.

3 Hydrology and Peak Flow Estimates

This section describes the Johnson Creek watershed delineation, the methods utilized for peak flow estimation and validation, and predicted climate change impacts to peak flows. Low summer flow conditions are not known and were not evaluated as it is beyond the scope of this PHD. Low-flow calculations should be considered to support step height design as part of the final hydraulic design (FHD).

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. The largest risk to bridges and buried structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and to maintain passability for all expected life stages and species in a system.

Johnson Creek does not have any historical flow data available and the nearest flow gage is the USGS Gage No. 12052210 located on the Big Quilcene River near Quilcene. This gage is approximately 15 miles west of the project location and has a drainage area of 49.4 square miles with a mean annual precipitation of 72.2 inches per year (PRISM Climate Group, Oregon State University 2021). Due to the distance from the project site, the order of magnitude difference in basin area, and significantly more annual rainfall, this site was determined unsuitable for site hydrologic analysis using basin transfer methods. Peak flow estimates were developed using MGSFlood (MGS Software LLC. 2021) and validated using the upper limit of the USGS regression equation for Region 3 (Mastin et al. 2017) as well as bankfull field indicators compared to 2-year peak flow. These are both hydrologic methods for ungaged locations described in WSDOT's *Hydraulics Manual* (2022).

The Johnson Creek watershed boundaries were delineated using 3-foot resolution LiDAR (USGS and Quantum Spatial 2018) and ArcHydro (ESRI n.d.) terrain-processing routines within ArcGIS. Channel-burning routines were not used because available depictions of hydrography, such as the National Hydrography Dataset and Ecology's stream dataset, are too coarse in resolution to adequately define the Johnson Creek channel. In addition to LiDAR terrain, culvert locations from the WDFW culvert database (WDFW n.d.-a) and utilities from the Kitsap County stormwater dataset (Kitsap County 2017) were used to guide watershed boundary delineation. The resulting area that contributes to Johnson Creek at the crossing (Subwatershed 1, see Section 2.2) is 388 acres (0.61 square mile) in size and extends approximately 1.5 miles north of SR 3 across areas of new urban development and suburban neighborhoods.

As-built plans of the Vinland Neighborhood were obtained from the City of Poulsbo Stormwater Division (Schager, pers. comm. 2022) to help determine the Johnson Creek watershed boundaries. In addition to the watershed directly contributing to the crossing, two subwatersheds were delineated that contribute flow to Johnson Creek downstream of the crossing within the project area. Subwatershed 2 (28.8 acres) contributes to an 18-inch culvert that discharges downstream of the crossing, and Subwatershed 3 (16.4 acres) contributes to a WSDOT detention facility that discharges just downstream of the crossing. The resulting flow estimates from these subwatersheds are provided in Table 6. These flows are used in the hydraulic model to accurately represent site conditions during high-flow events, see Section 5 for additional details.

The three delineated subwatersheds were used to develop inputs for MGSFlood. MGSFlood inputs are watershed areas associated with a combination of land cover and soil type. Land cover was estimated based on the National Land Cover Database (MRLC 2019a; Section 2.2), and soil type was estimated based on a combination of subsurface geology (NRCS USDA 2021; Section 2.3) and Soil Survey Geographic Database (SSURGO) soils (NRCS USDA 2021; Section 2.3). Consistent with MGSFlood guidance (MGS Software 2021), soils identified by SSURGO as hydrologic soil Group B used underlying geology to assign outwash and till soil designations.

The City of Poulsbo GIS data indicates that there are 27 stormwater detention best management practices (BMPs) within the watershed (Figure 2). These stormwater BMPs were not modeled explicitly as detention in MGSFlood; instead, the contributing impervious area to each BMP was treated in the MGSFlood inputs as forested. This approach resulted in five subbasins (four BMP areas and one overland flow area). See Appendix M for results from this analysis. MGSFlood hydrologic analysis for Subwatersheds 2 and 3 did not adjust landcover to represent effects of stormwater BMPs. Subwatersheds 2 and 3 were evaluated separately from Subwatershed 1 as their discharge points were below the crossing and Subwatersheds 2 and 3 are not influenced by Subwatershed 1.

USGS regression equation inputs include watershed area and mean annual precipitation. Mean annual precipitation of 40.8 inches was determined based on the 30-year climate normal (PRISM Climate Group, Oregon State University 2021). The USGS regression equation also provides lower and upper prediction intervals (PI_l and PI_u, respectively), acknowledging the uncertainty associated with this method. The upper limit of the USGS regression equation for Region 3 were used for validation because the watershed's percent impervious area (25 percent) is larger than the recommended standard in which regression equations should be used (5 percent).

MGSFlood was selected as the primary flow development method because it incorporates more refined hydrology methods based on land cover and soils. Calculations for MGSFlood, using a 15-minute timestep, and the USGS regression equation are provided in Appendix M. Peak flow estimate results are provided in Table 6. Subwatershed 1 MGSFlood results are generally within the 90 percent confidence level prediction interval of the USGS regression equation estimates, but higher than the central estimates (Q_u).

Top width results from a hydraulic model (SRH-2D) using the selected 2-year peak flow (27 cubic feet per second [cfs]) were compared to field-measured BFWs within the reference reach, collected during the November 30, 2021, site visit. These comparisons showed modeled top widths that were slightly larger than measured widths. Bankfull widths measured between 3 and 9 feet, where modeled 2-year flows produced top widths between 8 and 64-feet. This discrepancy is due to backwater created by the existing undersized culvert. However, away from the backwater influence modeled top widths were similar to those measured in the field. This comparison indicates that the estimated flows are generally consistent with those expected based on these field indicators.

WSDOT evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program (n.d.-a). All sites consider the projected 2080 percent increase throughout the design of the structure. Appendix G contains the projected increase information for the project site. The design flow for the crossing is 88 cfs at the 100-year storm event. The projected increase for the 2080, 100-year flow is 60.6 percent, yielding a projected 2080, 100-year flow of 141 cfs.

Table 6: Peak flows for Johnson Creek at SR 3

Mean recurrence interval	Selected Method - MGSFlood (cfs), Subwatershed 1	USGS regression equation (Region 3) ([PI_l], Q_u, [PI_u]) (cfs), Subwatershed 1	MGSFlood (cfs), Subwatershed 2	MGSFlood (cfs), Subwatershed 3
2	27	(6) 12 (25)	1.4	3.4
10	48	(12) 25 (52)	2.9	5.2
25	62	(15) 32 (68)	3.8	6.4
50	75	(16) 36 (82)	5.1	7.9
100	88	(18) 42 (96)	6.2	8.2
500	104	(22) 55 (135)	7.4	8.8
Projected 2080, 100	**(141; +60.6%)**	**([29] 67 [154]; +60.6%)**	(10; +60.6%)	(13; +60.6%)

4 Water Crossing Design

This section describes the water crossing design developed for SR 3 MP 52.21 Johnson Creek, including channel design, minimum hydraulic opening, and streambed design.

4.1 Channel Design

This section describes the channel design developed for SR 3 MP 52.21 Johnson Creek. The proposed design utilizes two typical cross sections, one for the pool sections and one for the glide sections, which are implemented over the 267 feet of channel grading proposed and described in further detail in Section 4.1.1. Additional information on the proposed alignment and gradient is provided in Sections 4.1.2 and 4.1.3, respectively.

4.1.1 Channel Planform and Shape

As mentioned in Section 2.7.1, the reference reach identified and considered in developing the preliminary design is located approximately 50 feet upstream of the SR 3 crossing and extends for another 100 feet upstream between SR 3 and the SR 3 on-ramp. Per the WCDG (Barnard et al. 2013), the planform and shape of each subreach within the proposed design were designed to mimic the reference reach with adjustments based on engineering and geomorphic judgements. Based on the observed reference reach, two channel types are proposed: glide and pool separated by a step. The proposed channel mimics the same juxtaposition of channel types as observed in the reference reach: long glides separated by periodic steps that define the head of an accompanying pool. Current channel processes in the reference reach allow for frequent floodplain inundation, incoming sediment load transport, existing pool maintenance, and periodic small instream wood recruitment. The proposed channel supports these same processes.

The proposed glide geometry includes a 7.5-foot BFW, a 0.75-foot bankfull depth, and floodplain benches on both sides to mimic the upstream reference reach (Figure 29). Modeled results for the 2-year event indicate shallow water (<0.25 feet) overtopping onto the floodplain, this is consistent with natural and proposed conditions in the upstream reference reach. The proposed pools have a similar width-to-depth ratio (approximately 5:1 to 7:1) as the narrower observed channel reaches.

The proposed glides have a similar width-to-depth ratio (approximately 9:1 to 10:1) as the wider observed reaches. The bottom of the glide channel is sloped at 10:1, the banks are sloped at 2:1, and the floodplain is sloped at approximately 20:1. The proposed pool geometry includes a 9.8-foot BFW and a 2.1-foot bankfull depth (Figure 30). Similar to the glide section, the bottom of the channel is sloped at a 10:1, the banks are sloped at 2:1, and the floodplain is sloped at approximately 20:1. The slope of the floodplain was selected to mimic the existing floodplain slopes in the reference reach.

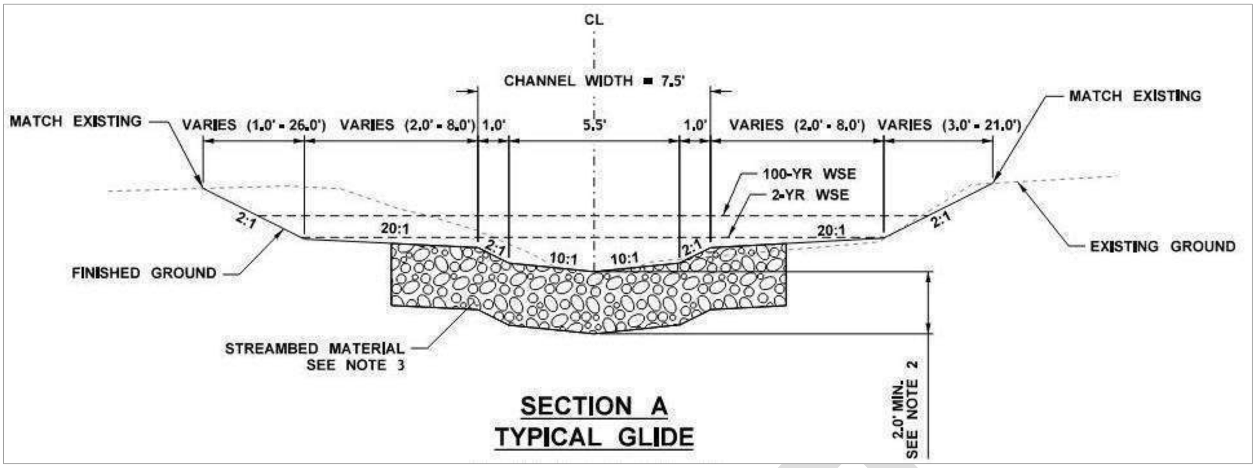


Figure 29: Design glide cross section

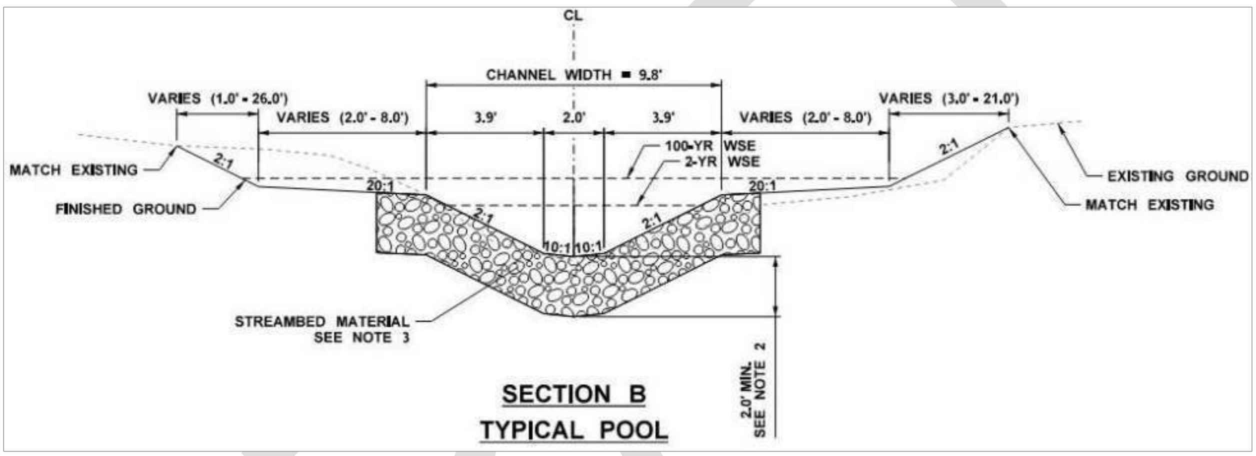


Figure 30: Design pool cross section

Meander bars and half-channel coarse bands are periodically placed along both banks to reduce the risk of entrainment against the structure, (discussed further in Section 4.3.1). Downstream of the 205-foot-long crossing, an approximate 2:1 slope ties in proposed grading to existing ground. Upstream of the crossing, the design team recommends that a headwall be installed similar to the existing condition with slopes that mimic the existing floodplain to tie into existing ground.

Outside of the structure, the floodplain width ranges from 20 to 30 feet (Figure 31, BFW 4 and BFW 3 are not within the reference reach but shown as a comparison to the surrounding reaches as a whole). See Appendix D for existing and proposed channel cross sections and planforms. The proposed channel will provide hydraulic characteristics similar to the reference reach. The 2-year event flows will engage the floodplain benches. Per Section 5.4, the 100-year velocity through the crossing is comparable to the natural-conditions velocity in the reference reach.

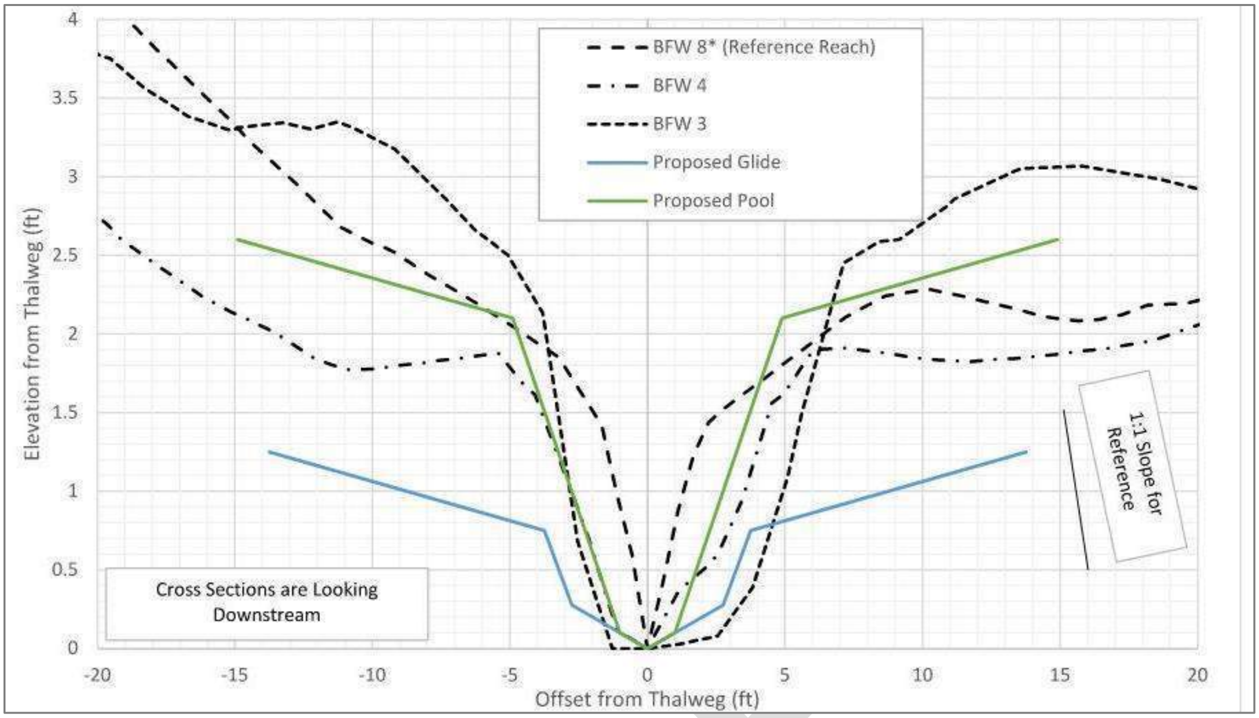


Figure 31: Proposed cross section superimposed with existing survey cross sections

A low-flow channel will be added in later project stages to connect habitat features together so that the project is not a low-flow barrier. The low-flow channel, which will be triangular, will be constructed as directed by the engineer in the field. Information on the size of streambed material, meander bars, and half-channel coarse bands is in Section 4.3.1.

4.1.2 Channel Alignment

A total of 267 feet of channel grading is proposed for the crossing, with 205 feet of regrading inside the proposed crossing and the remaining 62 feet outside of the crossing. In the existing conditions, the channel is skewed approximately 25 degrees from perpendicular to SR 3. Upstream channel grading maintains the existing alignment and catches with the existing floodplain approximately 15 feet upstream of the crossing. Downstream of the crossing, the existing channel is similar to the upstream section but is slightly more incised. Downstream channel grading roughly matches the existing alignment for approximately 50 feet before matching existing.

The proposed 267-linear-foot stream realignment maintains the approximately 25 degree skew to the roadway to maintain the general alignment of the existing stream. This will limit the amount of grading and disturbance to SR 3.

The new channel begins approximately 15 feet upstream of the proposed crossing to tie in-line to the existing thalweg. Approximately 10 feet is provided to transition between the existing grade and the proposed channel. Tie-in points were selected to minimize impacts to Johnson Creek and the existing wetlands around the creek. The proposed channel is relatively straight (sinuosity <1.1) with small meanders throughout the crossing. The size of meanders are limited by the crossing width, but are included to help dissipate velocity and promote natural channel processes through the crossing. The sinuosity of the existing channel is <1.1, as noted in Section 2.7.2.

The proposed downstream meander bend has a radius of curvature (Rc) between 20 to 70 feet, which approximates observed Rc in the existing channel (see Section 2.7.1). The proposed plan and profile sheets are in Appendix D, and vertical variability is discussed further in Section 4.1.3.

4.1.3 Channel Gradient

The stream immediately upstream of the existing culvert has a slope of 3.1 percent (see Appendix D, sheet CP1, average of Segment D and Segment E). The proposed channel has an overall slope of 3.6 percent. The WCDG (Barnard et al. 2013) recommends that the proposed crossing bed gradient be within 25 percent of the existing stream gradient upstream of the crossing. The overall slope ratio is 1.16. Within the proposed pool and glide transitions, the channel glides vary between a 1.5 to 2.0 percent gradient, giving slope ratios ranging from 0.48 to 0.65, respectively. These transitions create undulations in the profile that provide vertical variability.

The watershed-scale longitudinal profile of the channel shows a uniform slope of roughly 2 to 3 percent (Figure 28). The existing channel gradient from upstream of the crossing to downstream of the crossing is roughly 2.7 percent, with some existing channel segments (like the existing crossing) as steep as 3.4 percent. The reach around the crossing tends to be steeper than the overall watershed-scale profile, indicating that long-term degradation may occur as the profile adjusts to the equilibrium slope. This degradation could be up to 2 feet. However, the project reach is bounded upstream by the on-ramp crossing structure and bounded downstream by the off-ramp crossing structure. These structures act as grade control and limit the potential for any change in the profile around the crossing. Additional information on long-term aggradation and degradation is in Section 7.2.

4.2 Minimum Hydraulic Opening

The minimum hydraulic opening is defined horizontally by the hydraulic width and the total height is determined by vertical clearance and scour elevation. This section describes the minimum hydraulic width and vertical clearance; for discussion on the scour elevation see Section 7. Figure 32 illustrates the minimum hydraulic opening, hydraulic width, freeboard, and maintenance clearance terminology.

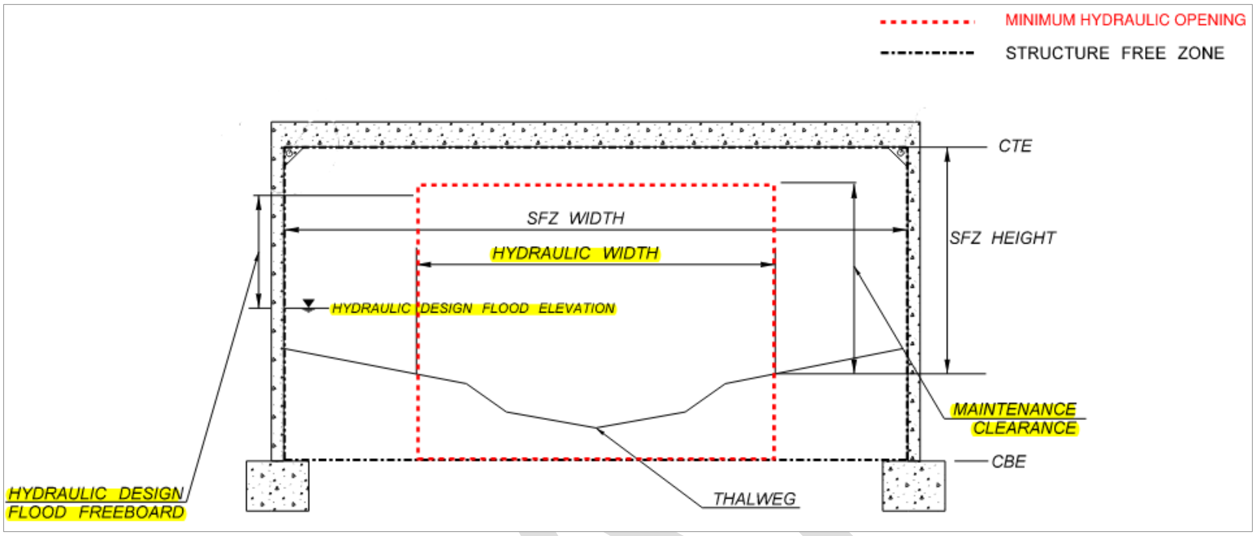


Figure 32: Minimum hydraulic opening illustration

4.2.1 Design Methodology

The proposed fish passage design was developed using WDFW's WCDG (Barnard et al. 2013) and WSDOT's Hydraulics Manual (2022). WDFW's WCDG contains methodology for five different types of crossings: No-Slope Culverts, Stream Simulation Culverts, Bridges, Temporary Culverts or Bridges, and Hydraulic Design Fishways. The permanent federal injunction allows for the use of the stream simulation method and the bridge design method unless unsurmountable circumstances exist onsite (constraints of landownerships or infrastructure for example). According to the WCDG, a bridge should be considered for a site if any of the following should be met: the FUR is greater than 3.0, the BFW is greater than 15 feet, the channel appears unstable, the slope ratio exceeds 1.25 between the existing channel and the new channel, the channel is debris prone, or the culvert is very long (beyond 10:1 length-to-width ratio).

Using the information presented below and guidance in the WCDG (Barnard et al. 2013) and the *Hydraulics Manual* (WSDOT 2022), the design team determined the unconfined bridge method through the crossing was the most appropriate. As noted in Section 2.7.2, the typical BFW is not greater than 15 feet. Section 2.7.4 notes that the existing channel grade is currently stable but has shown signs of downcutting downstream of the crossing and that the crossing itself could be acting as a grade control for the channel upstream. Section 2.7.5 mentions that the risk of lateral migration is low downstream of the crossing and moderate upstream. Additionally, the FUR is greater than 3.0 (Section 2.7.2.1), the proposed crossing is slightly above the recommended 10:1 length-to-width ratio (Section 4.2.4), and the overall slope ratio does not exceed 1.25 through the new crossing (Section 4.1.3). Section 4.1.3 notes that the channel has limited risk of channel degradation. Sections 2.7.5 and 4.1.1 note that the risk of horizontal migration is moderate upstream of the crossing and low downstream of the crossing. Finally, Section 4.2.3 shows that the minimum hydraulic opening, with a wider floodplain, is sufficient to allow for BFW increase over time due to climate resilience.

4.2.2 Hydraulic Width

The starting point for the minimum hydraulic width determination of WSDOT crossings is Equation 3.2 of the WCDG (Barnard et al. 2013), rounded up to the nearest whole foot. For this crossing, with a 7.5-foot BFW, a minimum hydraulic width of 11 feet was determined to be the minimum starting point. Although larger BFW values were measured in the field, the concurrence BFW of 7.5 feet was used because it best represents the median observed channel width. Since the culvert is long (beyond 10:1 length-to-width ratio), WSDOT requires a 30 percent increase in the hydraulic width, resulting in a minimum hydraulic width of 15 feet. Ultimately, the minimum hydraulic opening is driven by the accommodation of future channel sinuosity through the crossing and allowance for natural processes to occur under current flow conditions, and a 20-foot minimum hydraulic opening is proposed. Because of the skew to the road, the hydraulic opening measured along the road centerline is 22 feet. This hydraulic opening is driven by the geomorphic processes outlined in Section 4.1; it mimics the reference reach.

The 20-foot crossing allows for a minimum of 3.5 feet between the proposed crossing wall and the top of the proposed banks; if a narrower minimum hydraulic opening was chosen, the channel could begin to entrain against the walls. Additionally, the 20-foot minimum hydraulic opening will accommodate peak flows (100-year, 500-year, and projected 2080, 100-year MRI) and maintain an appropriate velocity ratio with adjacent reaches. Table 7 shows the minimum hydraulic opening required for each metric compared to the chosen minimum hydraulic opening. The first two metrics are calculated based on WCDG guidelines. Meander and valley width are measured from survey and field observations. The Q100 span is derived from model results. Associated vertical clearance requirements are in Section 4.2.3 and hydraulic length is in Section 4.2.4.

Table 7: Minimum hydraulic opening summary

Metric	Minimum Hydraulic Opening (ft)
Equation 3.2 of the WCDG	11
Length-to-Width Ratio	15
Q100 Span	20-90
Observed Meander Width	15-70
Valley Width	90-145
Chosen	20

Based on the factors described above, the design team determined a minimum hydraulic width of 20 feet is necessary to allow for natural processes to occur under current flow conditions. The projected 2080, 100-year flow event was evaluated. Table 8 compares the velocities of the 100-year and projected 2080, 100-year events.

Table 8: Main Channel Average Velocity comparison for 20-foot structure

Location	100-year Velocity (fps)	Projected 2080, 100-year Velocity (fps)	Velocity Ratio
Reference reach, transition from pool to glide (STA P14+99)	3.9	4.1	1.1
Upstream of structure (STA P14+07)	5.3	5.7	1.1
Through structure, transition from pool to glide (STA P13+21)	4.3	4.3	1.0
Downstream of structure (STA P12+02)	3.3	3.4	1.1

fps = feet per second

No size increase was determined to be necessary to accommodate climate change. For detailed hydraulic results see Appendix H.

4.2.3 Vertical Clearance

The vertical clearance under a structure is made up of two considerations: freeboard and maintenance clearance. Both are discussed below, and results are summarized in Table 9.

The minimum required freeboard at the project location, based on bankfull width, is 1 foot above the 100-year water surface elevation (WSE) (Barnard et al. 2013; WSDOT 2022). WSDOT's *Hydraulics Manual* requires 3 feet of freeboard for all structures greater than 20 feet and on all bridge structures unless otherwise approved by HQ Hydraulics.

WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSE and the projected 2080, 100-year WSE. The WSE is projected to increase by a maximum of 0.7 foot for the projected 2080, 100-year flow rate. The minimum required freeboard at this site will be applied above the projected 2080, 100-year WSE to accommodate climate resilience.

The second vertical clearance consideration is maintenance clearance. WSDOT HQ Hydraulics determines a required maintenance clearance if a height is required to maintain habitat elements, such as boulders or LWM. If there are no habitat elements requiring maintenance clearance to maintain, the maintenance clearance is only a recommendation by WSDOT HQ Hydraulics, and the region determines the maintenance clearance required.

The channel complexity features in Section 4.3.2 do not include elements of significant size and will not need to be maintained with machinery. If it is practicable to do so, a minimum maintenance clearance of 6 feet from the highest point in the cross section is recommended for maintenance and monitoring purposes but is not a hydraulic requirement. Maintenance clearance is measured from the highest streambed ground elevation within the horizontal limits of the minimum hydraulic width.

Table 9: Vertical clearance summary

Parameter	Downstream face of structure	Upstream face of structure
Station	P12+02.3	P14+07.0
Thalweg elevation (ft)	222.8	229.9
Highest streambed ground elevation within hydraulic width (ft)	224.3	232.4
100-year WSE (ft)	225.3	231.8
2080, 100-year WSE (ft)	226.0	232.5
Required freeboard (ft)	3	3
Recommended maintenance clearance (ft)	6	6
Required minimum low chord, 100-year WSE + freeboard (ft)	228.3	234.8
Required minimum low chord; 2080, 100-year WSE + freeboard (ft)	229.0	235.5
Recommended minimum low chord, highest streambed ground elevation within hydraulic width + maintenance clearance (ft)	230.3	238.4
Required minimum low chord (ft)	**229.0**	**235.5**
Recommended minimum low chord (ft)	**230.3**	**238.4**

4.2.3.1 Past Maintenance Records

As noted in Section 2.1, WSDOT Area 2 Maintenance was contacted to determine whether there are ongoing maintenance problems at the existing structure because of LWM racking at the inlet or sedimentation. The maintenance representative indicated that there was no record of LWM blockage and/or removal or sediment removal at this crossing.

4.2.3.2 Wood and Sediment Supply

The Johnson Creek watershed is comprised of a mix of low-density residential housing, high-density development, and forested lands. Most of the heavily forested lands that could contribute to LWM in Johnson Creek are located at the top of the watershed. The stream lacks the power to mobilize larger pieces of wood (1- to 2-foot diameter at breast height) and the relatively recently established trees in the immediate vicinity of the crossing make for a low supply of LWM in the system. Additionally, the stream's relatively narrow width facilitates the presence of channel-spanning wood rather than transportable LWM. See Section 2.6.4 for additional information on LWM in the system.

Sediment supply in the system appears to be moderate but not excessive. The system is dominated by small gravels and finer sediments likely due to backwater conditions at the culvert inlet. The design team expects that these sediments can be transported at low to moderate flows. The supply of larger sediment, transported at higher flows, is unknown. Field observations do not point to any excessive aggradation of materials; however, due to the lower grain sizes observed in the field, degradation of the channel may be an issue if there is a lack of larger sediment supply from upstream or if the invert elevation of the crossing changes.

4.2.4 Hydraulic Length

Currently, the proposed design shows a hydraulic length of 205 feet with a minimum hydraulic opening that was increased beyond the 30 percent guidance safety factor, as discussed in Section 4.2.2. An additional increase in width is not applicable due to the length of the crossing. At this time, no specific structure type has been recommended and effort should be made to minimize the proposed crossing hydraulic length to the extent practicable. These options will be evaluated by a geotechnical and structural engineer in the FHD.

4.2.5 Future Corridor Plans

Future corridor plans were requested from the WSDOT Project Engineer's Office by the design team. At the time of preparing this PHD, no corridor plans (if they exist) were provided.

4.2.6 Structure Type

No structure type has been recommended by WSDOT HQ Hydraulics. The layout and structure type will be determined at later project phases.

4.3 Streambed Design

This section describes the streambed design developed for SR 3 MP 52.21 Johnson Creek.

4.3.1 Bed Material

The bed stability approach was developed for the streambed aggregate material (SBM) design. This method uses empirical SBM stability equations to determine bed material incipient motion and selects the D_{50} or D_{84} (the particle size that is larger than 50 percent or 84 percent, .respectively, of the nearby material) mobilized at a particular design storm event to achieve stability per the WCDG (Barnard et al. 2013). Final gradations of the bed stability approach are provided based on standard WSDOT streambed aggregate sizes and compared against empirically based streambed aggregate distributions.

The calculations present the final selected gradation, the natural gradation based on natural distribution ratios, the results of the Fuller Thompson analysis (Barnard et al. 2013), and the average pebble counts for the project location, if collected. After performing hydraulic and substrate mobility calculations using various methods, a single D_{84} is selected. The D_{84} is the basis for the gradation of the SBM in the chosen location. A specific WSDOT standard gradation (WSDOT 2022) is then selected that most closely matches the final aggregate size. Results from the proposed 100-year and bankfull flood events were extracted from the proposed 2D hydraulic model. Maximum hydraulic values, such as flow area, critical depth, velocity, and hydraulic radius, were used as inputs to the incipient motion equations. The streambed aggregate mix calculations are in Appendix C.

As mentioned in Section 2.7.3, streambed material in the glide reaches is dominated by sand and silt (D_{50} <0.04 inch), and riffles are dominated by small gravel (D_{50} of 0.5 inch). Due to the small size of the existing material and using the approach above (specifically using the Modified Critical Shear Stress Design methodology), the suggested SBM is 15 percent WSDOT 4-inch streambed cobbles, 75 percent WSDOT standard streambed sediment, and 10 percent streambed sand for the proposed main channel. Table 10 summarizes the observed grain size distribution versus the proposed grain size distribution.

The proposed D_{50} is 20 percent larger than the observed riffle D_{50}. The observed riffle D_{50} is calculated from two pebble counts, each of which had a significant mode (10 to 12 percent) in sand-sized and finer sediments. This sand-sized and smaller fraction results in a lower D_{50} grain size, lower than if the sand-sized fraction had been excluded. The observed mode in sand is accounted for in the mobility analysis (Appendix C) by including 10 percent streambed sand in the proposed gradation; including streambed sand results in a lower proposed D_{50}.

To perform the mobility analysis for this gradation, a Shields parameter of 0.048 was selected for the proposed gradation. This was selected based on the D_{50} of the proposed gradation, the observed mode in sand, and Table E.1 from Appendix E of the U.S. Department of Agriculture Forest Service publication *Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings* (2008). There is uncertainty in the selection of the Shields parameter, but the entire proposed gradation is mobile at the 2-year event, regardless of the choice of Shields parameter. However, the design gradation includes 10 percent streambed sand to mimic the observed mode in sand and generally matches the observed gradation, creating stability without over coarsening of the bed. The proposed D_{84} is roughly double the size of the observed D_{84}, but the proposed D_{16} is slightly smaller than the observed D_{16}. This gradation ensures that the observed sand-sized fraction is present in the design, but the largest fraction of the bed material will remain stable and persist. The proposed gradient overall is similar to the existing slope; however, due to the steps incorporated into the bed morphology, the local slopes through the constructed channel, exclusive of the steps, is approximately 33 to 50 percent lower than the overall gradient. Most of the gradient through the reach is incorporated into the drop of each step.

Due to the sediment supply, this system is determined to be a low risk, according to the Streambed Material Decision Tree in WSDOT's *Hydraulics Manual* (2022). Jacobs suggests placing the material through and downstream of the crossing in lifts and washing it with fines to fill in void space; this will be considered further in the FHD. As mentioned in Sections 2.4 and 2.6.3, the stream width, depth, gradient, and substrate is suitable for rearing, migration, and spawning of resident and sea-run cutthroat trout and is modeled as suitable for migration and spawning of steelhead and coho.

The crossing will have several meander bars and half-channel coarse bands along the crossing walls to avoid entrainment, maintain channel shape, and maintain the sinuous thalweg over time. Initial calculations suggest the use of a mix of 25 percent 12- to 18-inch streambed boulders, 25 percent 12-inch streambed cobbles, 25 percent 8-inch streambed cobbles, and 25 percent WSDOT standard streambed sediment for the meander bar head. The meander bar tail and half-channel coarse bands are to be comprised of 70 percent WSDOT 8-inch streambed cobbles and 30 percent WSDOT standard streambed sediment. This provides a mix where the D_{50} of the meander bar tail material is approximately the same size at the D_{84} of the SBM. The proposed streambed mix for meander bars and half-channel coarse bands will be refined during the scour analysis in the FHD, and the meander bar design will be revisited per WSDOT meander bar guidance.

Table 10: Comparison of observed and proposed streambed material

Sediment size	Observed diameter for design (in)	Proposed diameter (in)	Meander bar head diameter (in)	Meander bar tail diameter (in)
$\mathbf{D_{16}}$	0.1	0.02	0.7	0.54
$\mathbf{D_{50}}$	0.5	0.60	4.23	2.25
$\mathbf{D_{84}}$	1.1	2.19	14.16	5.76
$\mathbf{D_{95}}$	3.0	2.56	16.80	7.3
$\mathbf{D_{100}}$	4.3	4.00	18	8.00

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for Johnson Creek at SR 3 MP 52.21.

4.3.2.1 Design Concept

Channel complexity is created by planform, bedforms, and LWM structures. The design channel consists of 267 feet of regraded channel with 205 feet of the regraded length within the crossing structure. The design channel is expected to develop and maintain a slightly sinuous planform, similar to the existing channel, and is enhanced as flow interacts with habitat features like meander bars and half coarse bands. Additional complexity, such as deformable grade control (small woody material intermixed with streambed material) is proposed at the inlet and the outlet and near station 13+50 and will be analyzed for performance and stability at the FHD. Deformable grade control is proposed to preempt headcut migration and plane bed development. The existing channel upstream and downstream of the crossing has a slightly sinuous planform (approximately 1.1), and this slight meandering is incorporated in the design channel. The sinuosity of the regraded channel is roughly 1.1.

In addition to a sinuous planform, complexity is added to the design channel using meander bars and half coarse bands and LWM placement. Meander bars are sited within the structure and angled to the channel centerline to prevent realignment of the channel thalweg adjacent to the structure wall and enable local scour and deposition. In addition to meander bars, half coarse bands are sited to create steps separating glides and pools and encourage small shifts in channel alignment. The coarse band extends roughly halfway across the channel to allow some channel movement and to preempt the band from acting as grade control. Steps in the channel profile created by half coarse bands will be immediately upstream of preformed pools. Step height is limited to 0.8 foot to prevent fish stranding.

LWM structures are placed in the regraded channel to create habitat, cover, and refugia. The LWM structures are placed to engage with channel flow at the bankfull flood event. LWM is specified in regraded channel reaches upstream and downstream of the crossing. Upstream of the crossing, much of the floodplain is mapped as wetland and ground conditions at site visits two and three were noticeable boggy. For this reason, the majority of the LWM structures are sited downstream of the crossing structure to limit disturbance to sensitive areas. Some areas downstream of the crossing are also mapped as wetland, but ground conditions are significantly drier.

LWM is designed according to WSDOT (2022) and Fox and Bolton (2007). The LWM should meet or exceed the sizing and characteristics of the reference reach by providing habitat, geomorphic function, sediment storage, bank stability, and hydraulic roughness. The existing LWM is limited both upstream and downstream of the existing culvert, with few pieces providing the key piece function. Due to the location and small size of the tributary, the site does not likely see recreational use for swimming or boating. Potential current and future use for fishing may occur, thus the LWM would be low impact to the recreational user.

The proposed LWM design (Figure 33) shows 55 pieces of wood to be placed within the 545-foot channel between the SR 3 on-ramp and off-ramp, with exception of the 205-foot segment for the roadway crossing. LWM placement is not limited to within the grading limits. No LWM is recommended to be placed under SR 3 due to the smaller size of the crossing. As of this time, the LWM design is conceptual and will need to be field verified in the FHD. Anchoring is anticipated until stability calculations are completed that indicate otherwise.

As discussed in Section 2.6.3, the size of the stream, substrate, and depth of water within the downstream reach is suitable for spawning, migration, and rearing of resident and anadromous fish species present in the system. Additionally, the size of the stream, substrate, and depth of water within the upstream reach is suitable for rearing and migration and is excellent for foraging opportunities for juvenile salmonids of all species; however, spawning habitat within the upstream reach is limited due to the dominance of deep silt and organic material within the substrate. The LWM design increases this habitat by providing structural habitat through pools and refugia formation as well as shade and food-sourcing promotion of aquatic organisms for fish. The proposed design meets the 75th percentile of the number of key pieces and exceeds the total number of pieces as estimated by Fox and Bolton (2007). Due to using LWM sized appropriately for the system, roughly 43 percent of the total volume suggested by Fox and Bolton (2007) is met by the proposed design. Table 11 lists a comparison of the Fox and Bolton targets and the proposed design values of LWM. Appendix F provides the LWM calculations.

Table 11: Project reach LWM loading

LWM Loading Component	Design Criteria (75th percentile)[a]	Proposed Design
Total pieces (quantity)	31	55
Total volume (cubic yards)	105.4	45.1
Key Pieces (quantity)	9	9

a. Calculated based on Fox and Bolton (2007) metrics using a project reach of 267 feet and a bankfull width of 7.5 feet.

Two types of LWM structures are proposed:

Type 1: This surface placed LWM structure consists of five wood pieces. One 30-foot-long piece with a root wad and four 8-foot-long pieces with root wads. The root wad of the 30-foot piece is placed in the channel and ballasts the four smaller pieces. The boles of the smaller pieces are directed into the channel. Two pieces are parallel to each other and pointed slightly upstream. The remaining two pieces are subparallel and pointed slightly downstream. This structure provides bank protection, cover, and local scour to create pools. Four Type 1 structures are proposed.

Type 2: This surface-placed LWM structure consists of one 20-foot-long piece, four 12.5-foot-long pieces, and two 8-foot-long pieces. All pieces have root wads. This is a two-sided structure, meaning that it includes wood placed on both sides of the design channel. On the left bank (looking downstream), the root wad of the 20-foot piece is placed in the channel, pointed slightly upstream. This piece provides ballast to two 12.5-foot pieces and one 8-foot piece. The boles of all three of these pieces are placed in the channel pointing slightly downstream. On the opposite bank and slightly downstream, the 12.5-foot piece is placed on top of two 8-foot pieces. The boles of all three pieces are placed in the channel. The 12.5-foot piece points slightly upstream while the 8-foot pieces cross near the tip and point downstream. This configuration is intended to deflect flow (using the root wad of the 20-foot piece) toward the downstream boles on the opposite bank. This flow deflection on both banks creates local scour and deposition that may facilitate and maintain preformed pools. Five Type 2 structures are proposed.

All structures are anticipated to remain stable up to and through the 100-year flow event by virtue of the structures' weight, configuration, and orientation, which must be verified in the FHD and fortified if necessary through soil ballast or anchoring. All LWM stability calculations will be completed in the FHD to validate the stability of all LWM structures and help determine whether anchoring is needed. Neither structure type is designed to change channel planform, but facilitate in-channel change, such as local scour and deposition. Portions of the LWM that are placed on the floodplain also prevent avulsion. Preformed pools are recommended around larger rootwads to anticipate future scour.

The proposed coarse bars provide habitat value through localized scour pools and flow deflection, which creates variable flow patterns within the structure. All pools, preformed or not, would provide resting areas for the fish listed in Section 2.4. Additionally, all of the proposed LWM is surface placed and self-ballasted rather than buried, which allows for a lesser grading and clearing impact. With a smaller footprint, more riparian vegetation can remain in place and continue to function properly, with well-developed root mass to help stabilize banks, a well-developed canopy to provide shade and LWM recruitment, and a developed understory.

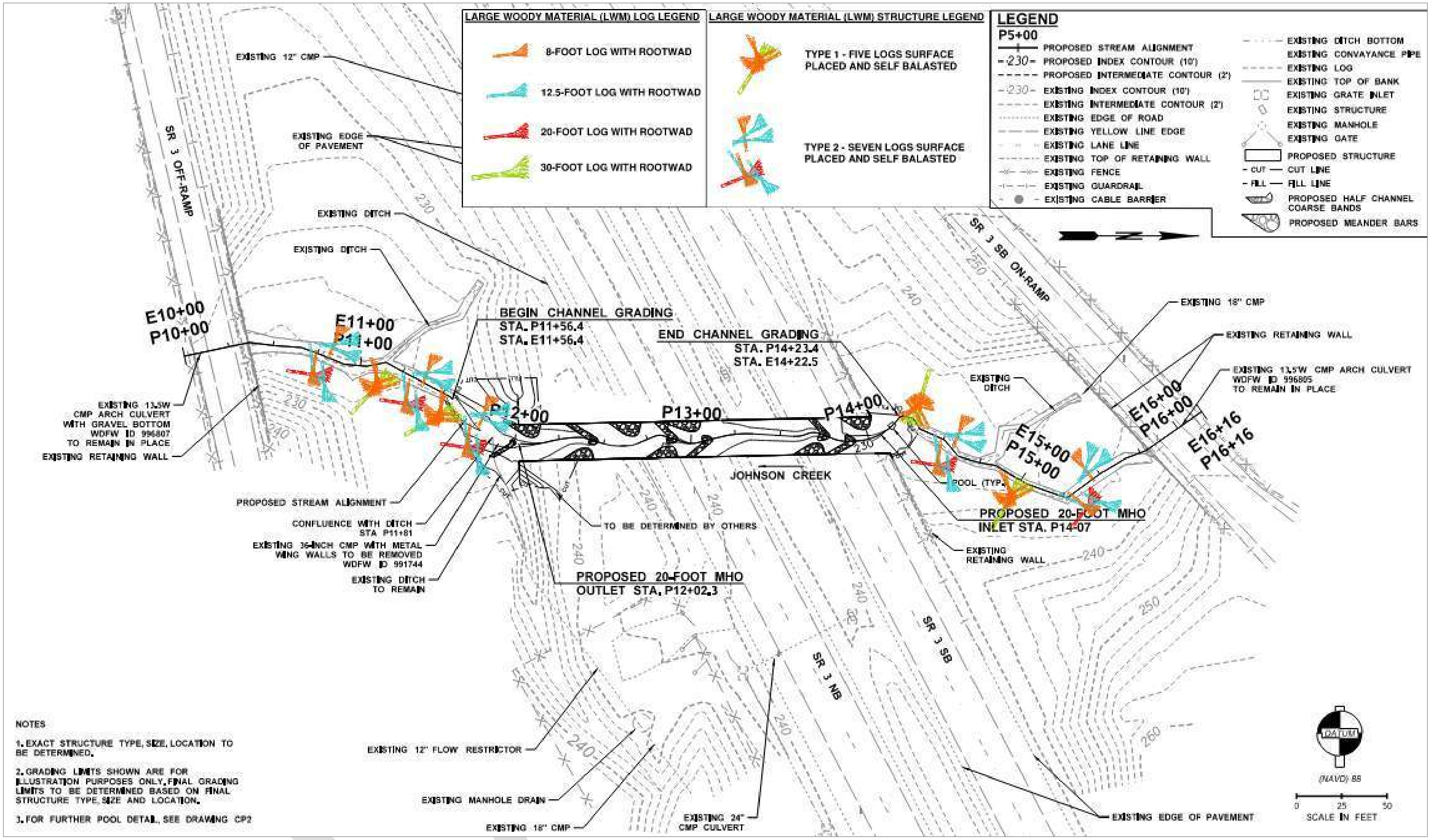


Figure 33: Conceptual layout of habitat complexity

4.3.2.2 Stability Analysis

Large wood stability analysis will be completed at final design.

5 SRH-2D Hydraulic Analysis

The hydraulic analysis of the existing and proposed SR 3 MP 52.21 Johnson Creek crossing was performed using the U.S. Bureau of Reclamation's SRH-2D Version 3.3.1 computer program (2020). Pre- and post-processing for this model was completed using SMS Version 13.1.16 (Aquaveo 2021).

Three scenarios were analyzed for determining stream characteristics for Johnson Creek with the SRH-2D models: (1) existing conditions with the 36-inch-diameter, 211 foot-long CMP, (2) natural conditions with the existing culvert artificially enlarged and modeled as a 40- by 20-foot box culvert to eliminate backwatering, and (3) proposed conditions with a 20-foot-wide proposed structure beneath SR 3. See Appendix H for a complete set of output figures.

5.1 Model Development

This section describes the development of the model used for the hydraulic analysis and design.

5.1.1 Topographic and Bathymetric Data

The channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the WSDOT Project Engineer's Office, which were developed from topographic surveys performed by WSDOT in September 2021. The survey data were supplemented with LiDAR data (USGS and Quantum Spatial 2018). Proposed channel geometry was developed from the proposed grading surface created by Jacobs. All survey and LiDAR information is referenced against the North American Vertical Datum of 1988 (NAVD 88).

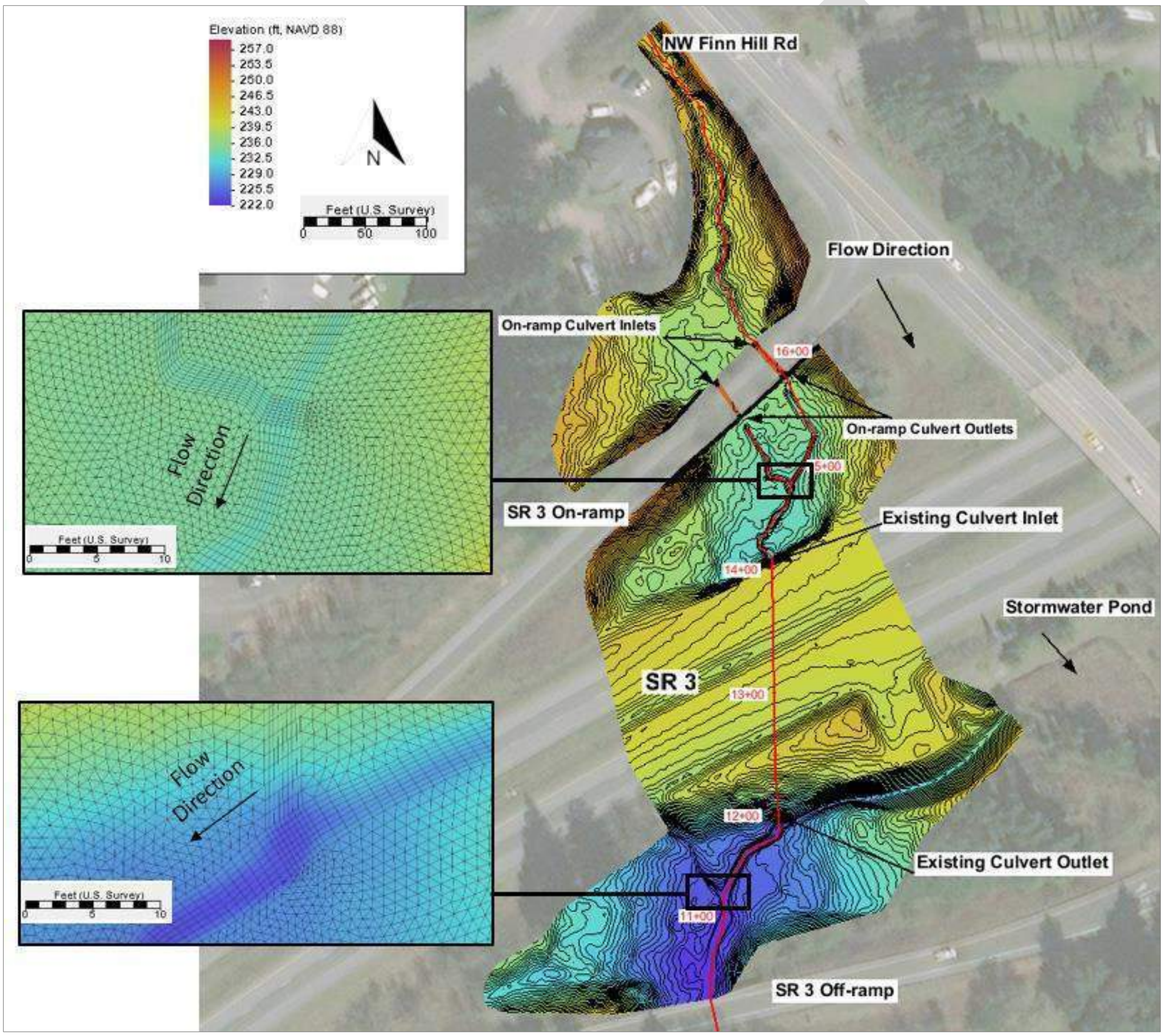
There are several structural hydraulic controls within the study area. Approximately 130 feet upstream of the SR 3 crossing and 160 feet downstream, the creek is conveyed through culverts beneath on- and off-ramp embankments to SR 3 at NW Finn Hill Road. Both of these bounding culverts are steel arch culverts with native channel SBM. The on-ramp culvert measures 13.5 feet wide by 8.5 feet tall, and the off-ramp culvert measures 13.5 feet wide by 8 feet tall. Additionally, roughly 10 feet downstream of the existing SR 3 crossing outlet, a small stormwater pond overflow ditch confluences with Johnson Creek. This overflow ditch will not be altered as part of the proposed design.

5.1.2 Model Extent and Computational Mesh

The existing model mesh includes approximately 48,000 elements across an area of approximately 3 acres. The mesh was constructed with quadrilaterals that are approximately 0.8 foot by 1.3 foot in the main channel, while the overbank mesh was constructed with triangles varying in size from 0.2 square foot near the main channel to 7.9 square feet at the exterior of the model domain. The main channel is comprised of 8 elements laterally spanning the BFW to sufficiently capture details of the channel within the mesh. For the 500-year event, the mesh was extended approximately 270 feet to the west and 255 feet to the east along the SR 3 roadway to capture flow overtopping the road.

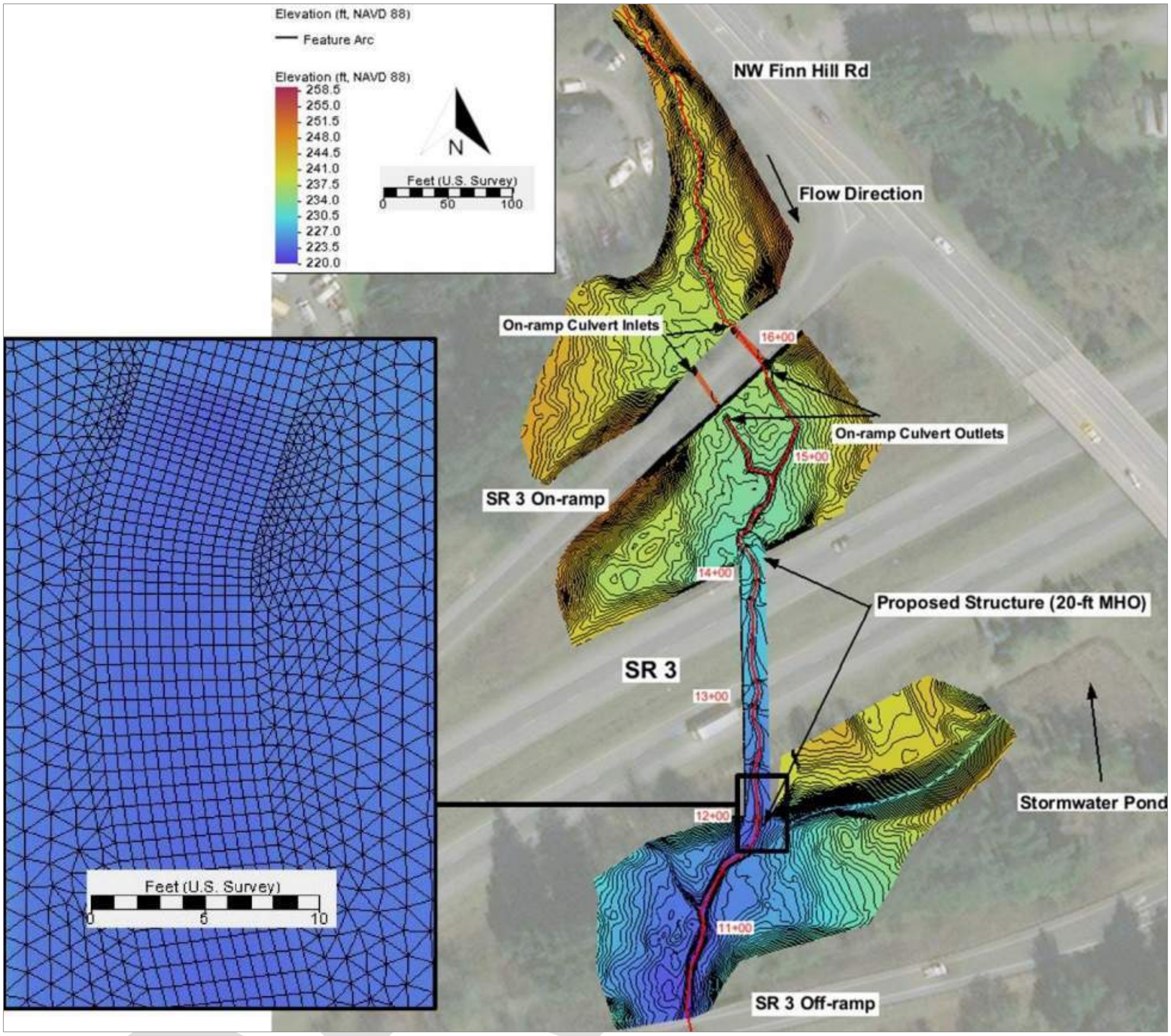
The model extends approximately 475 feet upstream of the SR 3 crossing to capture the hydraulic impacts of all the culverts in the study area. The downstream extent of the model is roughly 175 feet downstream of the SR 3 crossing outlet. Figure 34 shows the extent of the model mesh for the existing conditions. The lateral and longitudinal extent of the mesh captures the hydraulic processes present at the crossing.

The proposed model mesh covers the same extents as the existing model mesh. Elements outside of the proposed crossing were removed to reduce model run times. Figure 35 shows the extent of the model mesh for the proposed conditions.



Note: Alignment is the existing alignment as shown on Sheet CE1 in Appendix D.

Figure 34: Existing-conditions and natural-conditions computational mesh with underlying terrain



Note: Alignment is the proposed alignment as shown on Sheet CR1 in Appendix D.

Figure 35: Proposed-conditions computational mesh with underlying terrain

5.1.3 Materials/Roughness

The roughness coefficient is a composite value representing two forms of flow resistance: form drag and skin friction. Both affect hydraulic conditions (such as WSE, velocity, and shear stress) and the energy that is available to transport sediment. Form drag represents large-scale impediments to flow, including bends, point bars, LWM, or vegetation, and is highly dependent on flow depth and velocity. Skin (or grain) friction are the individual particle characteristics interacting with fluid at the fluid/soil boundary. Discrete roughness elements will be incorporated during the FHD.

Four Wolman pebble counts, two in the upstream reach and two in the downstream reach were performed, described further in Section 2.7.3. A variety of empirical relationships exist between surface sediment size and roughness; however, Limerinos (1970) was used to characterize grain roughness and Aldridge and Garrett (1973) was used to characterize form drag. The Limerinos equation is defined as follows:

$$n = \frac{(0.0926 * R^{\frac{1}{6}})}{1.16 + 2.0 * log(\frac{R}{D_{84}})}$$

Where;

R = Hydraulic Radius (ft)

D_{84} = Particle diameter of which 84 percent of the gradation is smaller than based on the intermediate axis.

The existing channel roughness was determined using the average substrate sediment size information from the two downstream pebble counts, which were selected for use in this analysis, resulting in an *n*-value of 0.029. The *n*-value was increased by roughly 50 percent to 0.043 to account for observed obstructions, such as protruding wood, root mass, and boulders, based on guidance from Aldridge and Garrett (1973). This is consistent with the Chow (1959) approach for isolating roughness characteristics and aggregating them. Existing floodplain roughness was determined based on the prevalence and density of observable drag elements, such as wood, vegetation, and floodplain irregularity, with guidance from Arcement et al. (1989) and Chow (1959). The existing culvert beneath SR 3 was assigned a roughness value of 0.020, consistent with weathered corrugated steel pipe materials, and the upstream on-ramp culvert (18 inches) was assigned a value of 0.018 based on weathered corrugated aluminum pipe materials.

The proposed channel, meander bar, and course band roughness values are based on the SBM size (see Section 4.3.1) and Limerinos' (1970) equation for roughness (*n)* (shown above) for small gravel to medium-sized boulder streams, where R is the hydraulic radius and D_{84} is the grain size that 84 percent of the sampled bed material is smaller than. Refer to Appendix E for the roughness calculations.

LWM was modeled in the proposed-conditions model as an obstruction layer. Obstruction objects reduce the flow on the water through the model by applying a drag force. A drag coefficient of 1.3 was applied to all of the obstruction arcs to represent a circular cylinder. A porosity of 0.4 was applied to all of the obstruction arcs to represent a balance between the more porous roots wads and the less porous trunk pieces.

Spatially, variable roughness values for existing and proposed conditions are summarized in Table 12 and on Figure 36 and Figure 37.

Table 12: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Material	Manning's *n*	
	Existing Conditions	Proposed Conditions
Existing Floodplain (Arcement et al. 1989; Chow 1959)	0.093	0.093
Proposed Floodplain (Arcement et al. 1989; Chow 1959)	—	0.045
Existing Channel (Arcement et al. 1989; Chow 1959)	0.043	0.043
Proposed Channel (based on Limerinos 1970)	—	0.045
Roadway	0.02	0.02
Managed right-of-way	0.04	—
Existing Culvert	0.020	---
Meander Bars (based on Limerinos 1970)	—	0.101
Coarse Bands (based on Limerinos 1970)	—	0.061

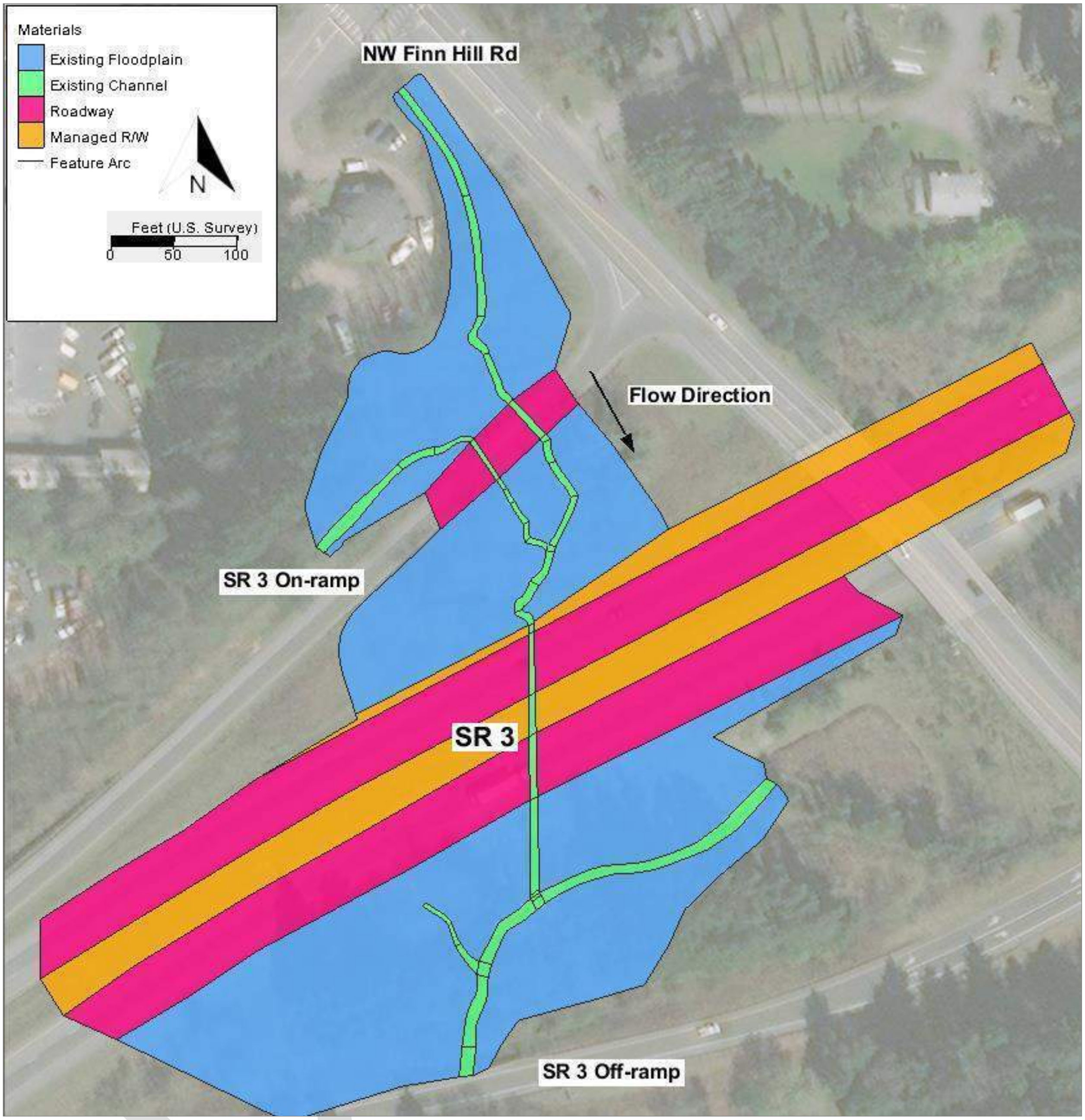


Figure 36: Spatial distribution of existing-conditions and natural-conditions roughness values in the SRH-2D model

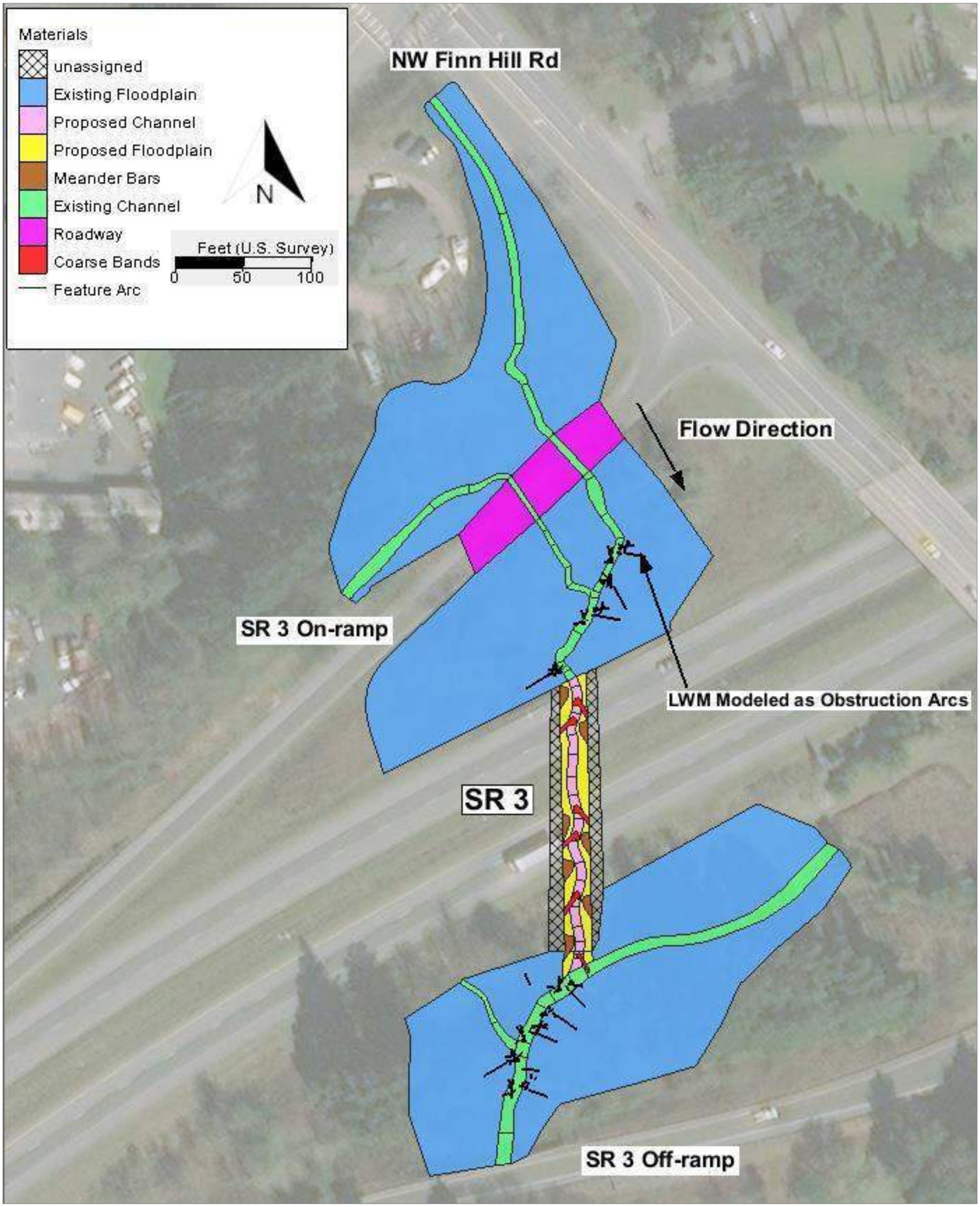


Figure 37: Spatial distribution of proposed-conditions roughness values in the SRH-2D model

5.1.4 Boundary Conditions

The boundary conditions for the existing-, natural-, and proposed-conditions models include two upstream inflows, two downstream inflows, and a single outflow boundary. Flow in Subwatershed 1 was split between a primary channel, to the north, and a much smaller roadside ditch to the west. As described in Section 3, separate subwatersheds were delineated for the stormwater pond and culvert inflow locations downstream of the crossing. Table 6 in Section 3 details the peak flow rates for each of the three subwatersheds.

Two culverts under the SR 3 on-ramp were included in all models. These culverts and the existing culvert under SR 3 were modeled using the integrated HY-8 Culvert Analysis Program (HY-8; Federal Highway Administration 2021). Figure 38, Figure 39, Figure 40, and Figure 41 show the HY-8 culvert hydraulic inputs for these crossings. The culvert listed on Figure 39 was originally input as a 12-inch CMP culvert; however, updated as-built information shows the culvert is an 18-inch CMP culvert. The hydraulic impact between these culverts is negligible; however, it will be updated during the FHD. The culvert on Figure 40 represents the arch culvert that passes flow beneath the SR 3 on-ramp, the maximum arch culvert size available in HY-8 is 142 inches by 91 inches. Although it is slightly smaller than the existing culvert, the culvert sizes are similar and were used for modeling purposes. Because the model is run to steady state, the impacts of this change in culvert size is minimal. The Manning's roughness value of n = 0.027 was selected for the culvert shown on Figure 40. This roughness value was selected to best represent the natural bed and corrugated metal sides of the culvert. The SR 3 culvert was modeled as an artificially widened 40- by 20-foot concrete box culvert to simulate natural conditions. The proposed crossing was modeled as a hole in the mesh, which allows the crossing to be represented with vertical walls.

The boundary condition locations are shown on Figure 42 for existing conditions, Figure 43 for natural conditions, and Figure 44 for proposed conditions. The outflow boundary condition rating curve used for all modeled conditions is shown on Figure 45. The outflow rating curve is based off Manning's normal depth equation for flow through a 13.5- by 8.5-foot arch culvert under the SR 3 off-ramp. A roughness value of n = 0.020 was used to represent the CMP culvert and channel slope of 0.025 feet per foot.

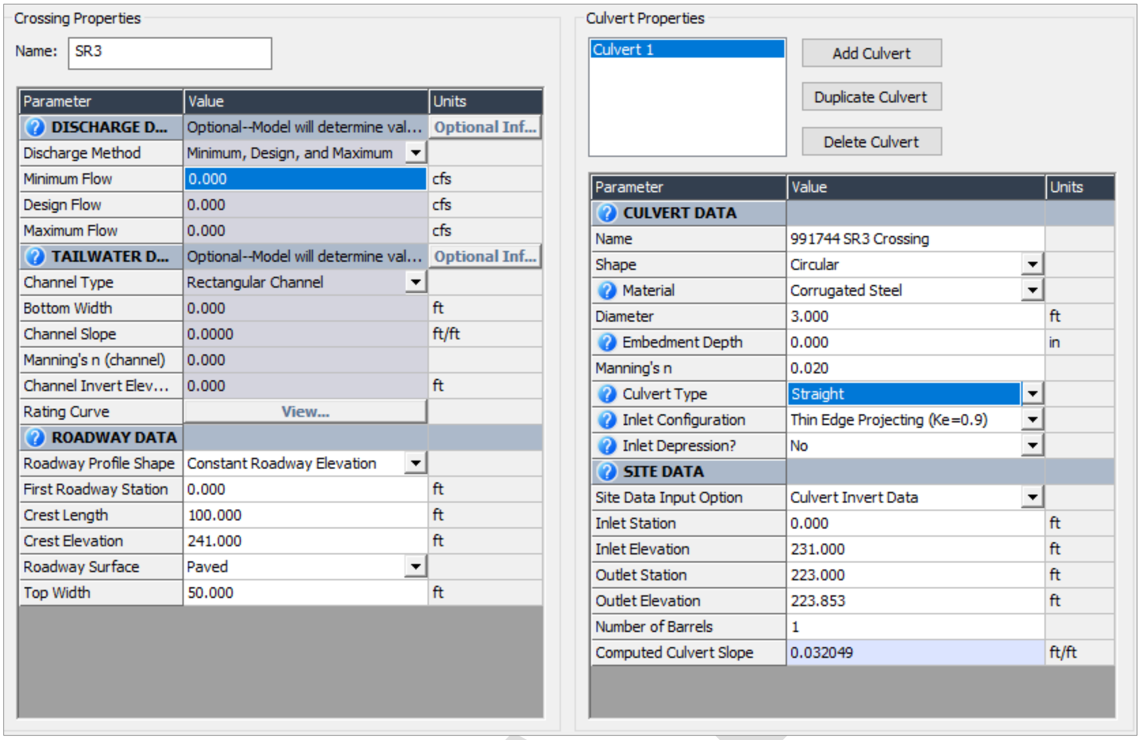
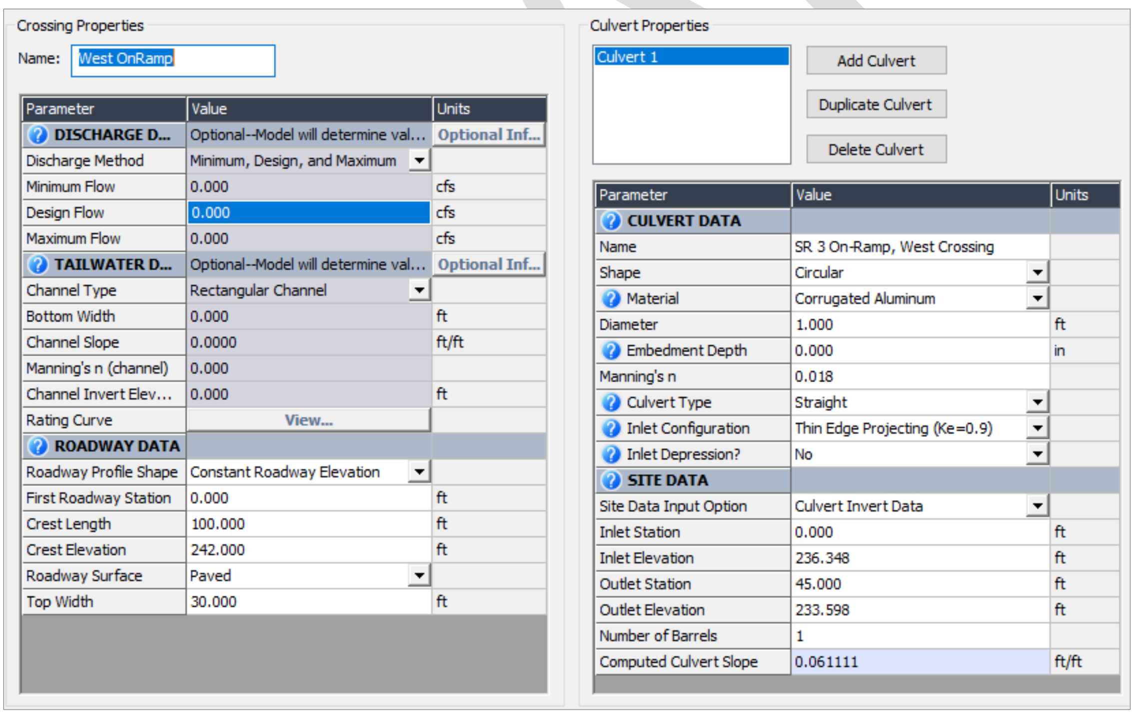
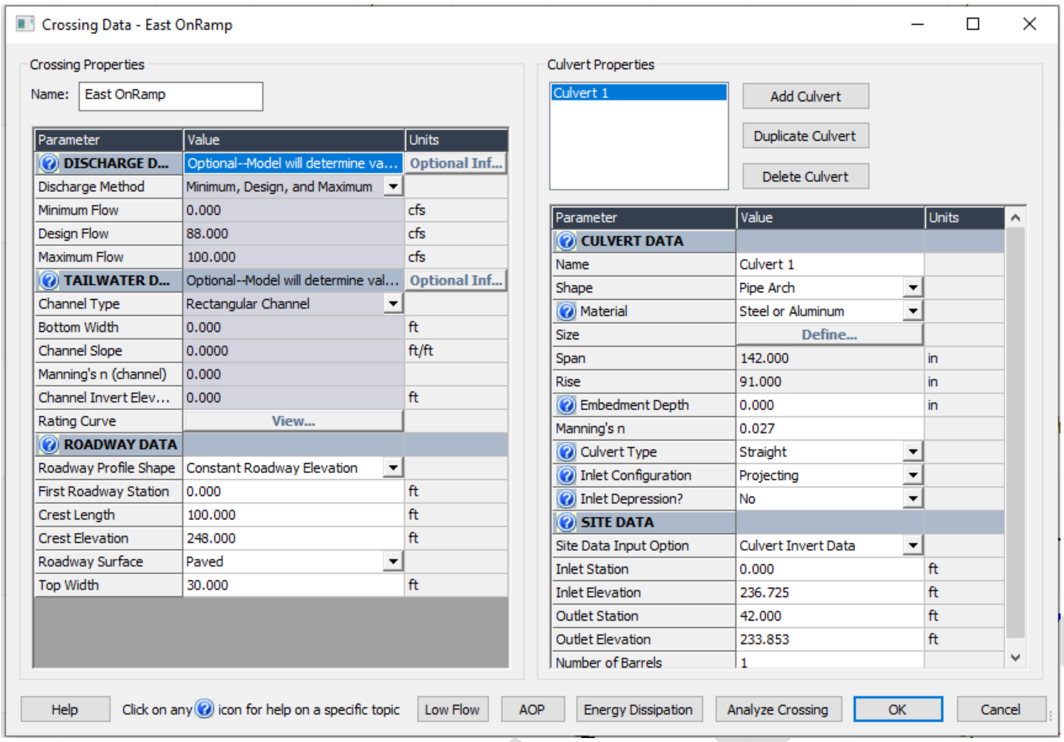


Figure 38: HY-8 culvert parameters for existing SR 3 crossing



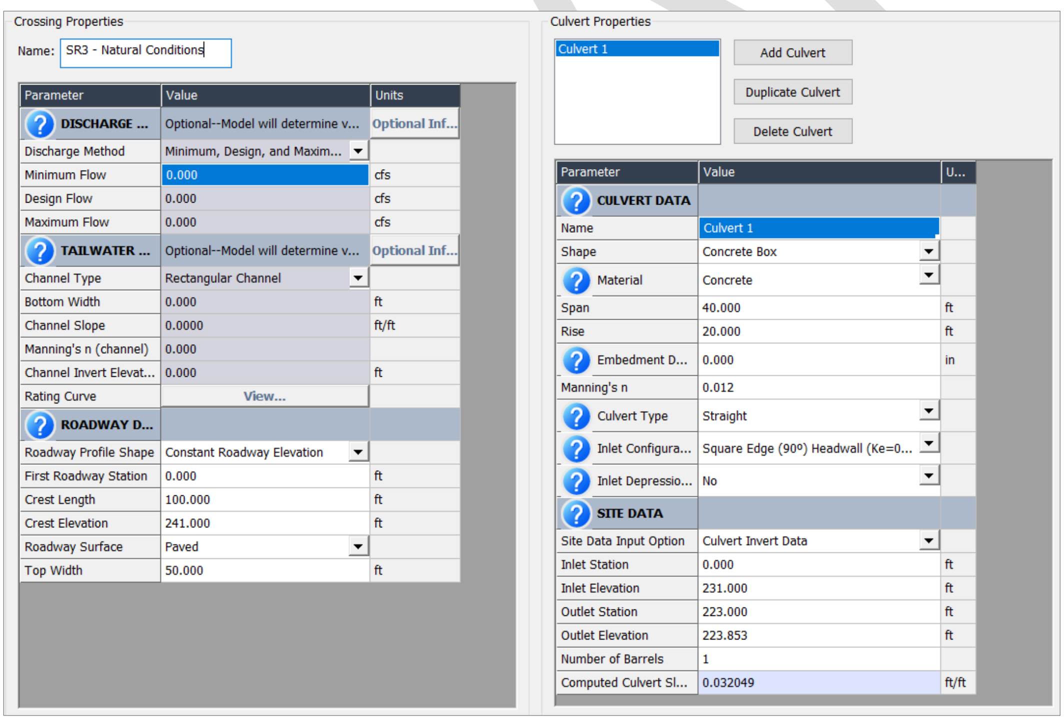
Note: Culvert will be updated to an 18-inch CMP in the FHD to match as-builts.

Figure 39: HY-8 culvert parameters for western on-ramp culvert



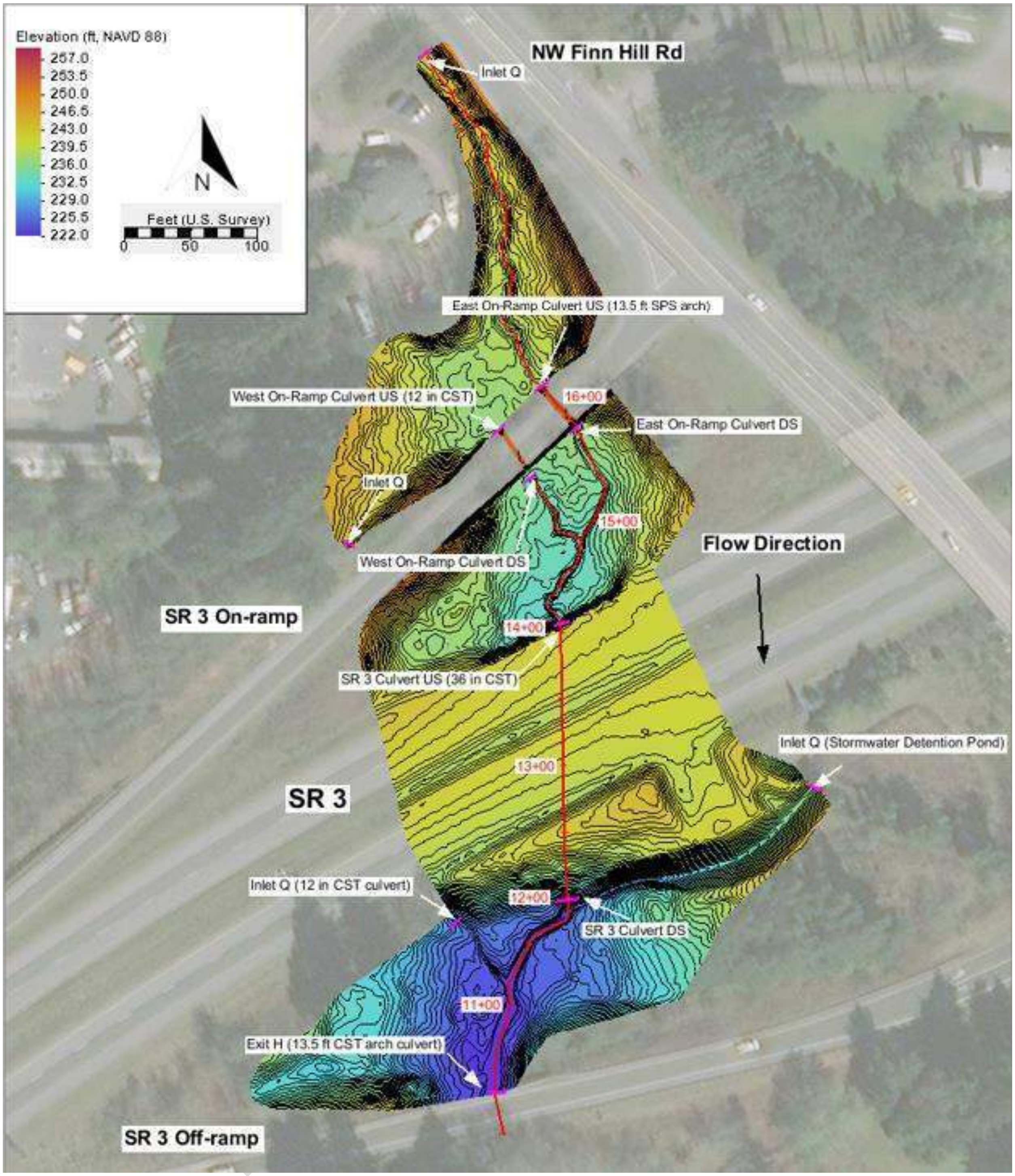
Note: Arch culvert rise/spans are predefined in HY-8, and 142 inches by 91 inches is the largest size available.

Figure 40: HY-8 culvert parameters for eastern on-ramp culvert



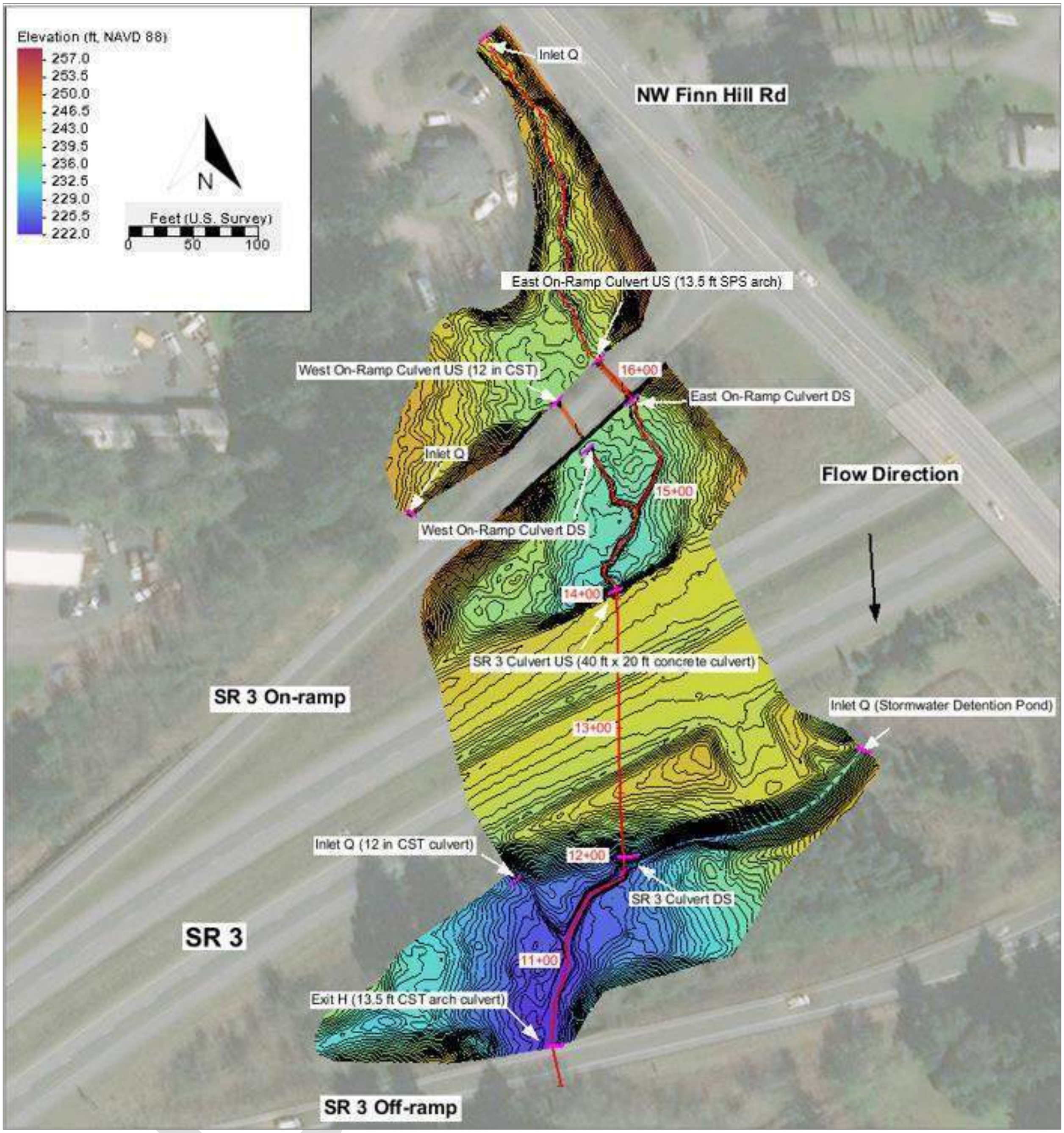
Note: Natural conditions culvert size and roughness are not based on a physical structure but rather is intended to remove any backwater directly upstream caused by the SR 3 culvert. See Section 5.3 for more details of the natural conditions model.

Figure 41: HY-8 culvert parameters for natural conditions SR 3 culvert



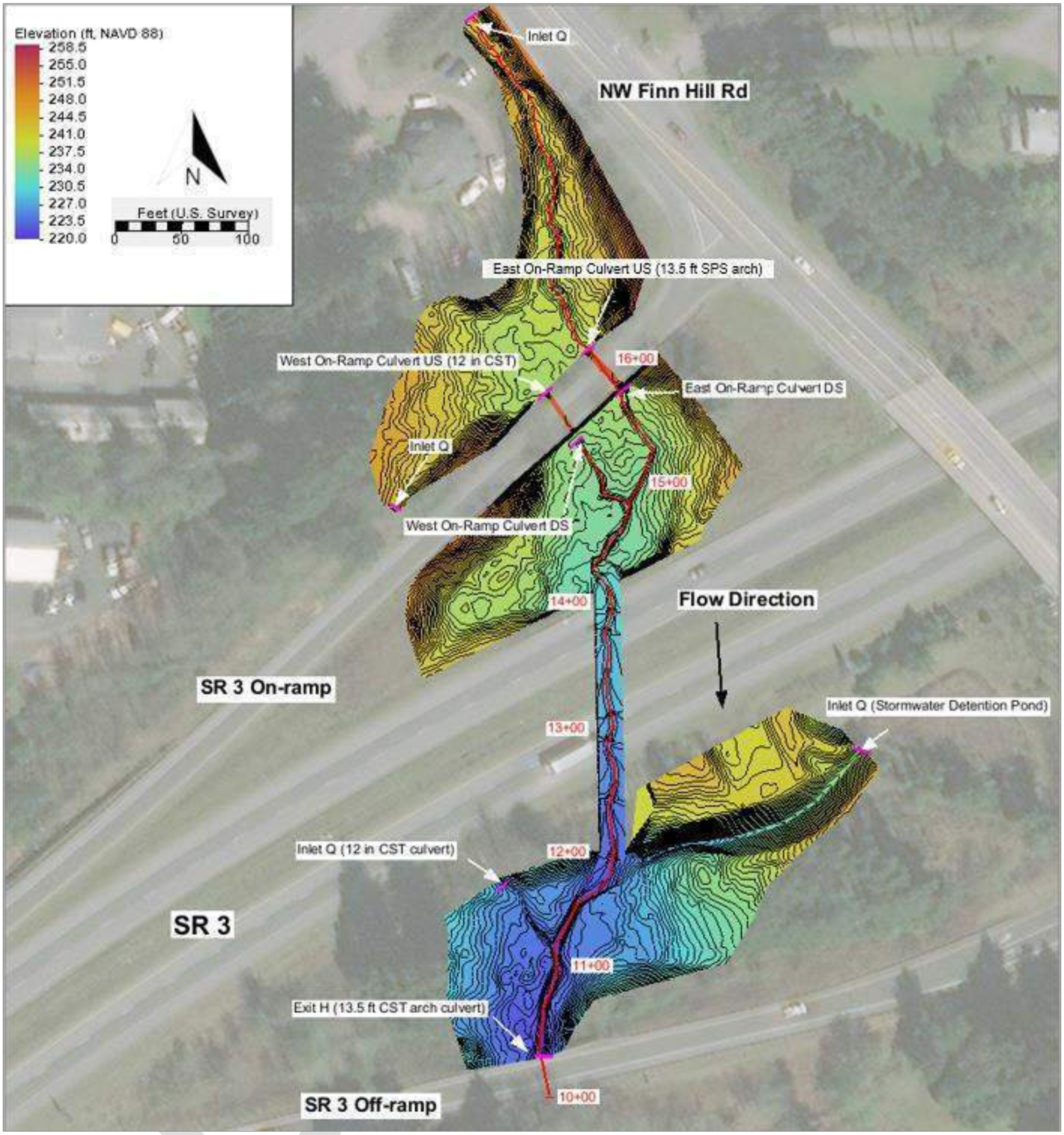
Note: The western on-ramp culvert and the downstream inlet will be updated to 18-inch CMP in the FHD to match as-builts. (Alignment is the existing alignment as shown on Sheet CE1 in Appendix D.)

Figure 42: Existing-conditions boundary conditions



Note: The western on-ramp culvert and the downstream inlet will be updated to an 18-inch CMP in the FHD to match as-builts. (Alignment is the existing alignment as shown on Sheet CE1 in Appendix D.)

Figure 43: Natural-conditions boundary conditions



Note: The western on-ramp culvert and the downstream inlet will be updated to an 18-inch CMP in the FHD to match as-builts. (Alignment is the proposed alignment as shown on Sheet CR1 in Appendix D.)

Figure 44: Proposed-conditions boundary conditions

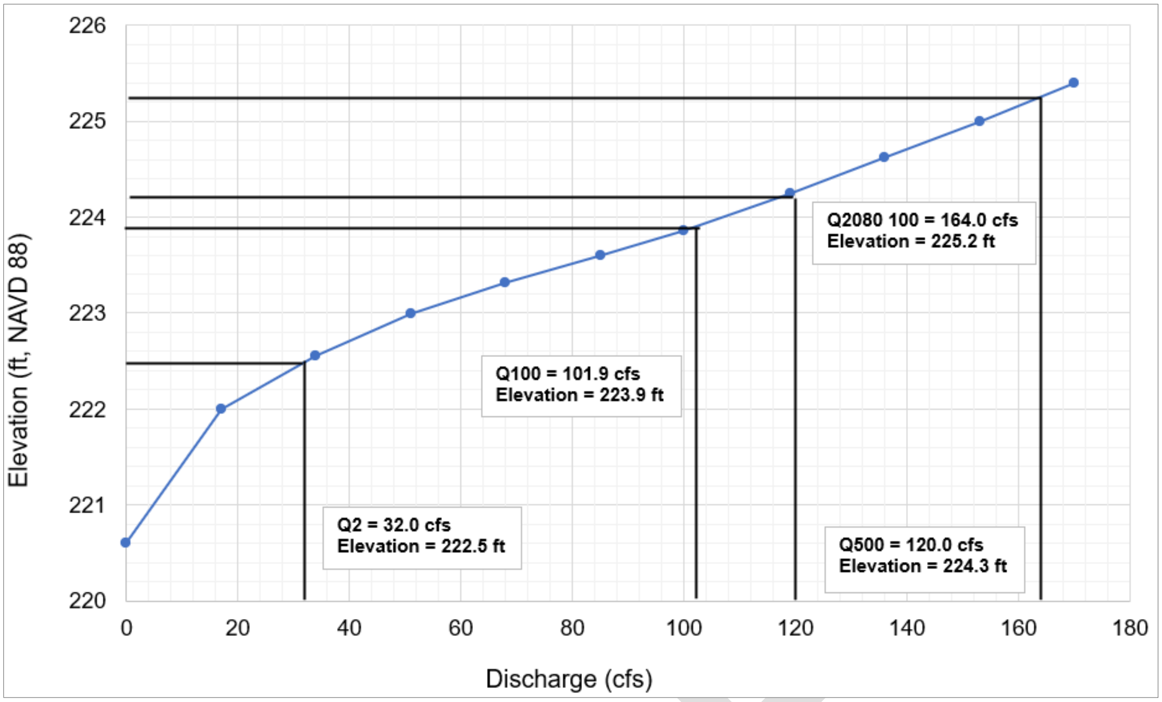


Figure 45: Downstream outflow boundary condition normal depth rating curve

5.1.5 Model Run Controls

Jacobs ran the existing-, natural-, and proposed-conditions scenarios for 3 hours; the outlet of the model domain reached a stable steady-state condition after approximately 0.5 hour. Appendix I contains additional information regarding model stability. Other parameters were set as follows:

- Start time is default 0.0 hour
- Time step is default 0.1 seconds
- End time is 3.0 hours
- Initial conditions value is default dry
- Flow module was default parabolic and parabolic turbulence of 0.7
- Output frequency is set at 5 minutes

5.1.6 Model Assumptions and Limitations

The hydraulic model is limited by the quality, density, and accuracy of each data input and how the information is parameterized by the model. Notable limitations of the hydraulic model are summarized below:

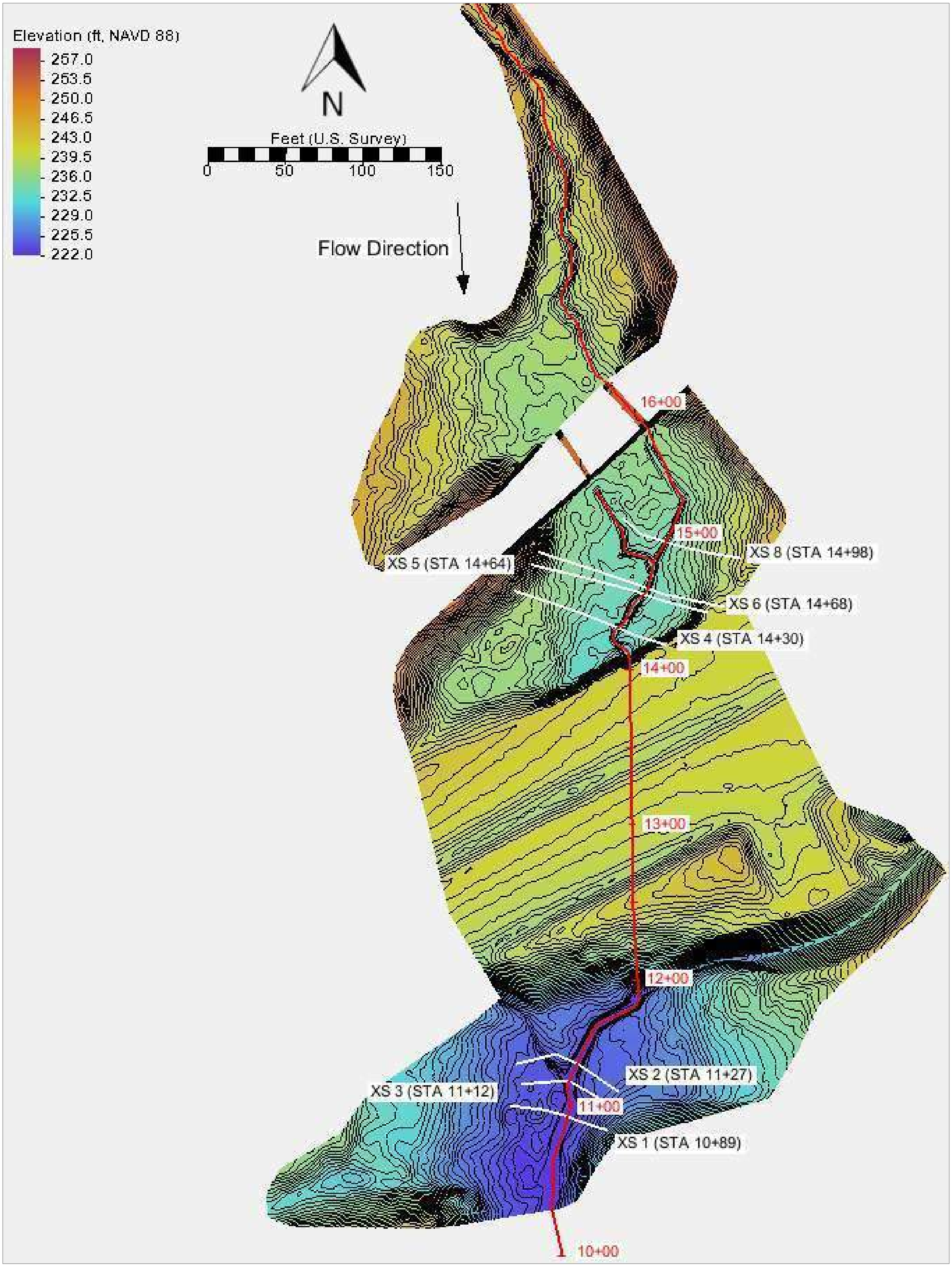
- The outflow boundary condition is represented as a stage outflow based on a rating curve for flow through the off-ramp arch-culvert.
- There is an assumed flow distribution between the two inflow boundary conditions, because hydrologic analysis was not performed on each subbasin. The assumed flow distribution is based on each respective basin area.
- The model assumes constant flow resistance across flow depths. In reality, at lower-flow depth, friction is a larger component of fluid motion.

- The model is fixed bed, all features are static. In reality, at flood stage, aggradation and degradation create pools and gravel bars and change the channel morphology.
- The hydraulic model does not account for infiltration loss or hyporheic inflow.
- Due to changes in the proposed alignment, the existing- and proposed-conditions alignment stationing differ throughout the model domain. See Appendix D for alignment comparisons.
- Maximum arch culvert size in HY-8 is 142 inches by 91 inches. This dimension was used for the eastern on-ramp culvert (Figure 40).

5.2 Existing Conditions

The existing-conditions model was run for the 2-year, 100-year, and 500-year MRI events. The average hydraulic results of the WSE, water depth, velocity, and shear stress are reported in Table 13 and the respective cross section locations are shown on Figure 46. Figure 47 and Figure 48 show the water surface profile and a typical section from the reference reach for the scenarios that were evaluated, respectively. The water surface profile shows that SR 3 is overtopped at the 500-year MRI, but not at the 2-year or 100-year MRIs. The existing culvert across SR 3 is undersized at flows over the 2-year MRI, resulting in the culvert being submerged (pressure flow) and creating backwater conditions upstream of the crossing to the SR 3 on-ramp.

The cross section on Figure 48 shows that there is high floodplain connectivity throughout the upstream reach. Flows from all MRIs overtop the stream banks and inundate the floodplain. The depth of floodplain inundation is increased by the backwatered conditions of the existing culvert. At the 100-year MRI, average channel velocities range from 4.8 fps downstream of the existing SR 3 crossing to 0.5 fps upstream of the inlet of the SR 3 crossing. This is again reflective of the backwatering upstream of the crossing. Table 14 reports average velocities at the 100-year MRI throughout a variety of locations. Figure 49 and Figure 50 show plan views of the upstream and downstream 100-year MRI velocities, respectively. Velocities are highest, up to 8 fps, at the outlets of the eastern on-ramp culvert and SR 3 culvert. Average main channel shear stresses upstream of the existing crossing are low at high-flow events due to backwatering. Below the crossing, average channel shear stresses range from 0.2 -0.9 pounds per square foot at the 100-year MRI. Shear stresses are highest at the outlet of the SR 3 culvert, reflecting the high velocity at that location. Additional existing-conditions model results are in Appendix H.



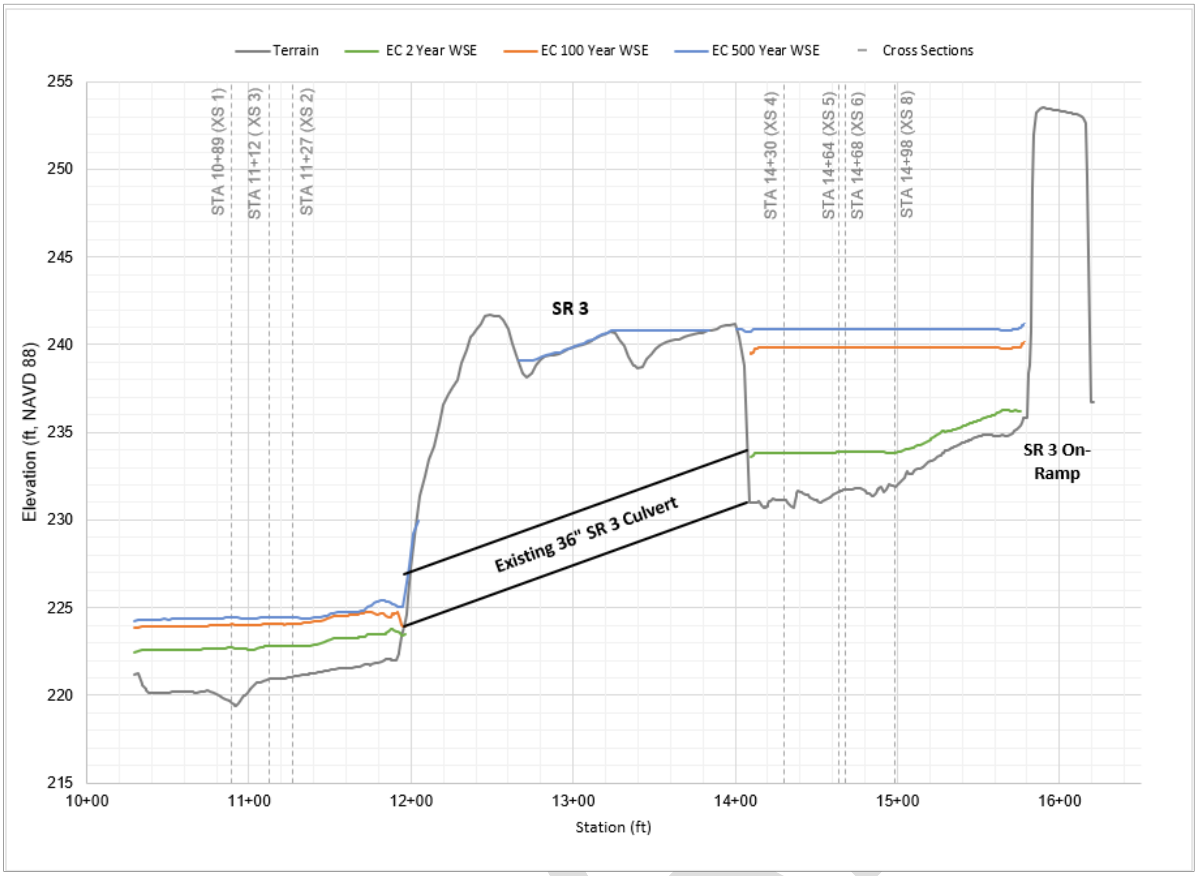
Note: Alignment is the existing alignment as shown on Sheet CE1 in Appendix D.

Figure 46: Locations of cross sections used for results reporting

Table 13: Average main channel hydraulic results for existing conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year
Average WSE (ft, NAVD 88)	XS 8 (STA E14+98)	233.9	239.8	240.9
	XS 6 (STA E14+68)	233.9	239.8	240.9
	XS 5 (STA E14+64)	233.9	239.8	240.9
	XS 4 (STA E14+30)	233.9	239.8	240.9
	Structure	N/A	N/A	N/A
	XS 2 (STA E11+27)	222.8	224.1	224.4
	XS 3 (STA E11+12)	222.8	224.1	224.5
	XS 1 (STA E10+89)	222.7	224.0	224.4
Max depth (ft)	XS 8 (STA E14+98)	1.9	7.9	9.0
	XS 6 (STA E14+68)	2.2	8.2	9.2
	XS 5 (STA E14+64)	2.4	8.3	9.4
	XS 4 (STA E14+30)	3.0	9.0	10.1
	Structure	N/A	N/A	N/A
	XS 2 (STA E11+27)	1.7	3.0	3.4
	XS 3 (STA E11+12)	1.9	3.2	3.6
	XS 1 (STA E10+89)	3.4	4.7	5.1
Average velocity (fps)	XS 8 (STA E14+98)	4.5	0.9	0.6
	XS 6 (STA E14+68)	1.9	0.7	0.6
	XS 5 (STA E14+64)	1.7	0.6	0.6
	XS 4 (STA E14+30)	0.8	0.5	0.4
	Structure	N/A	N/A	N/A
	XS 2 (STA E11+27)	0.6	4.8	4.3
	XS 3 (STA E11+12)	0.2	3.0	2.9
	XS 1 (STA E10+89)	0.1	1.6	1.7
Average shear (lb/SF)	XS 8 (STA E14+98)	1.2	0.0	0.0
	XS 6 (STA E14+68)	0.2	0.0	0.0
	XS 5 (STA E14+64)	0.1	0.0	0.0
	XS 4 (STA E14+30)	0.0	0.0	0.0
	Structure	N/A	N/A	N/A
	XS 2 (STA E11+27)	0.6	0.9	0.7
	XS 3 (STA E11+12)	0.2	0.4	0.4
	XS 1 (STA E10+89)	0.1	0.2	0.3

Main channel extents were approximated based on inspection of topographic breaks upstream of the crossing and based on the 2-year event water surface top widths downstream of the crossing.



Note: Alignment is the existing alignment as shown on Sheet CE1 in Appendix D.

Figure 47: Existing-conditions water surface profiles

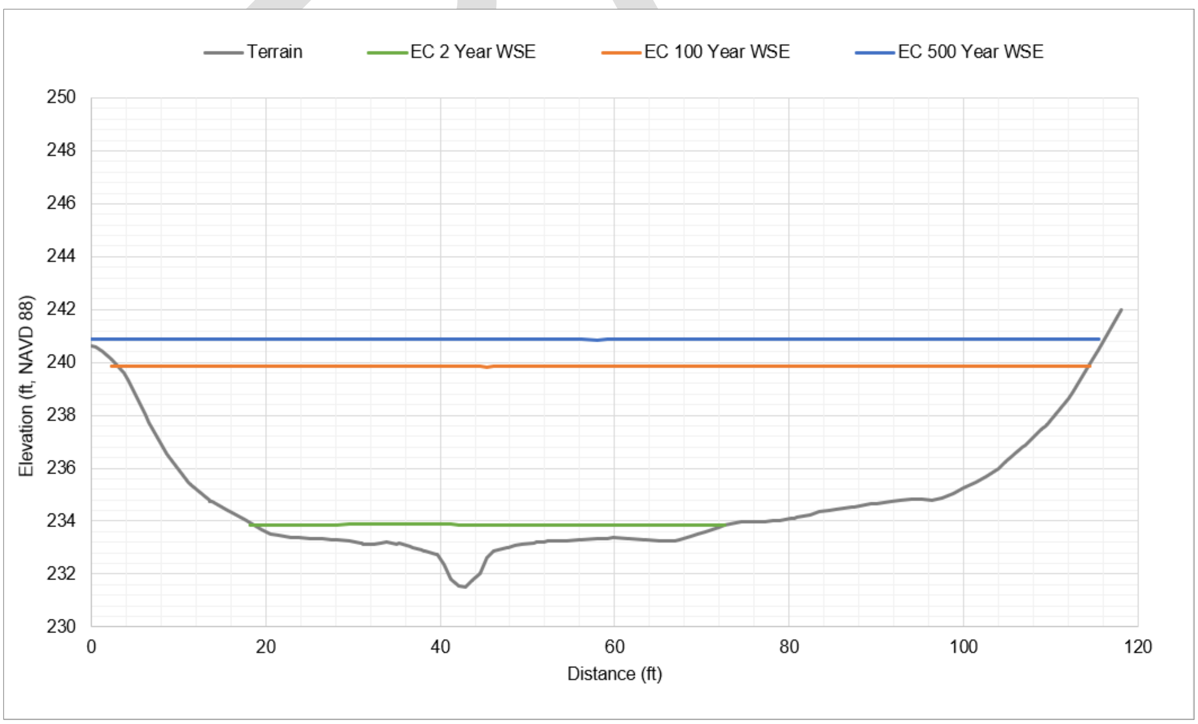
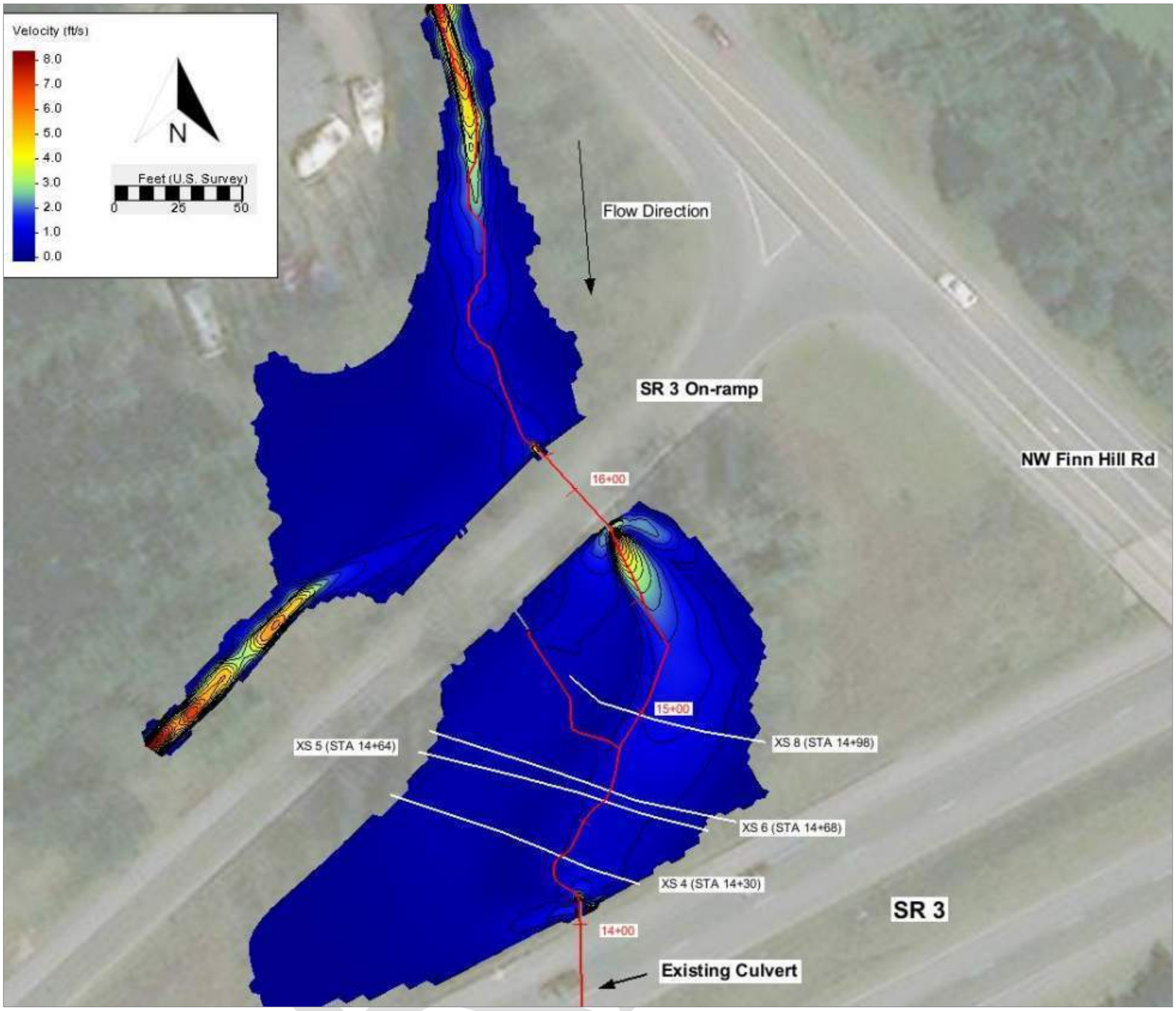
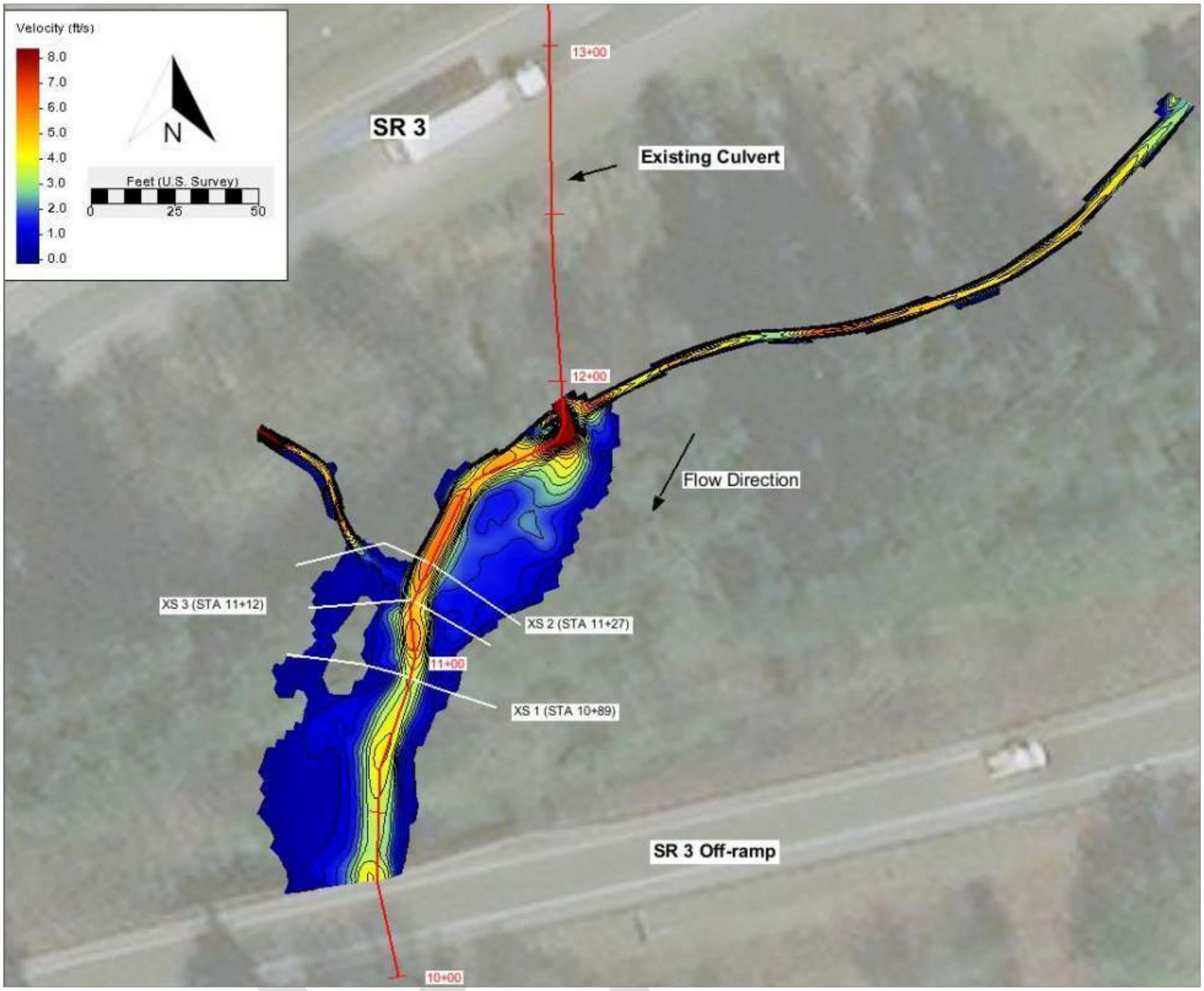


Figure 48: Typical upstream existing channel Cross section 5 (STA 14+64)



Note: Alignment is the existing alignment as shown on Sheet CE1 in Appendix D.

Figure 49: Existing-conditions upstream reach 100-year velocity map with cross section locations



Note: Alignment is the existing alignment as shown on Sheet CE1 in Appendix D.

Figure 50: Existing-conditions downstream reach 100-year velocity map with cross section locations

Table 14: Existing-conditions average channel and floodplains velocities

Cross section location	Q100 average velocities (fps)		
	LOB[a]	Main channel	ROB[a]
XS 8 (STA E14+98)	0.3	0.9	0.8
XS 6 (STA E14+68)	0.4	0.7	0.5
XS 5 (STA E14+64)	0.3	0.6	0.5
XS 4 (STA E14+30)	0.3	0.5	0.6
Structure	N/A	N/A	N/A
XS 2 (STA E11+27)	0.8	4.8	1.3
XS 3 (STA E11+12)	0.8	4.8	1.3
XS 1 (STA E10+89)	0.6	3.0	0.9

a. Right overbank (ROB)/left overbank (LOB) locations were approximated based on inspection of topographic breaks upstream of the crossing and based on the 2-year event water surface top widths downstream of the crossing

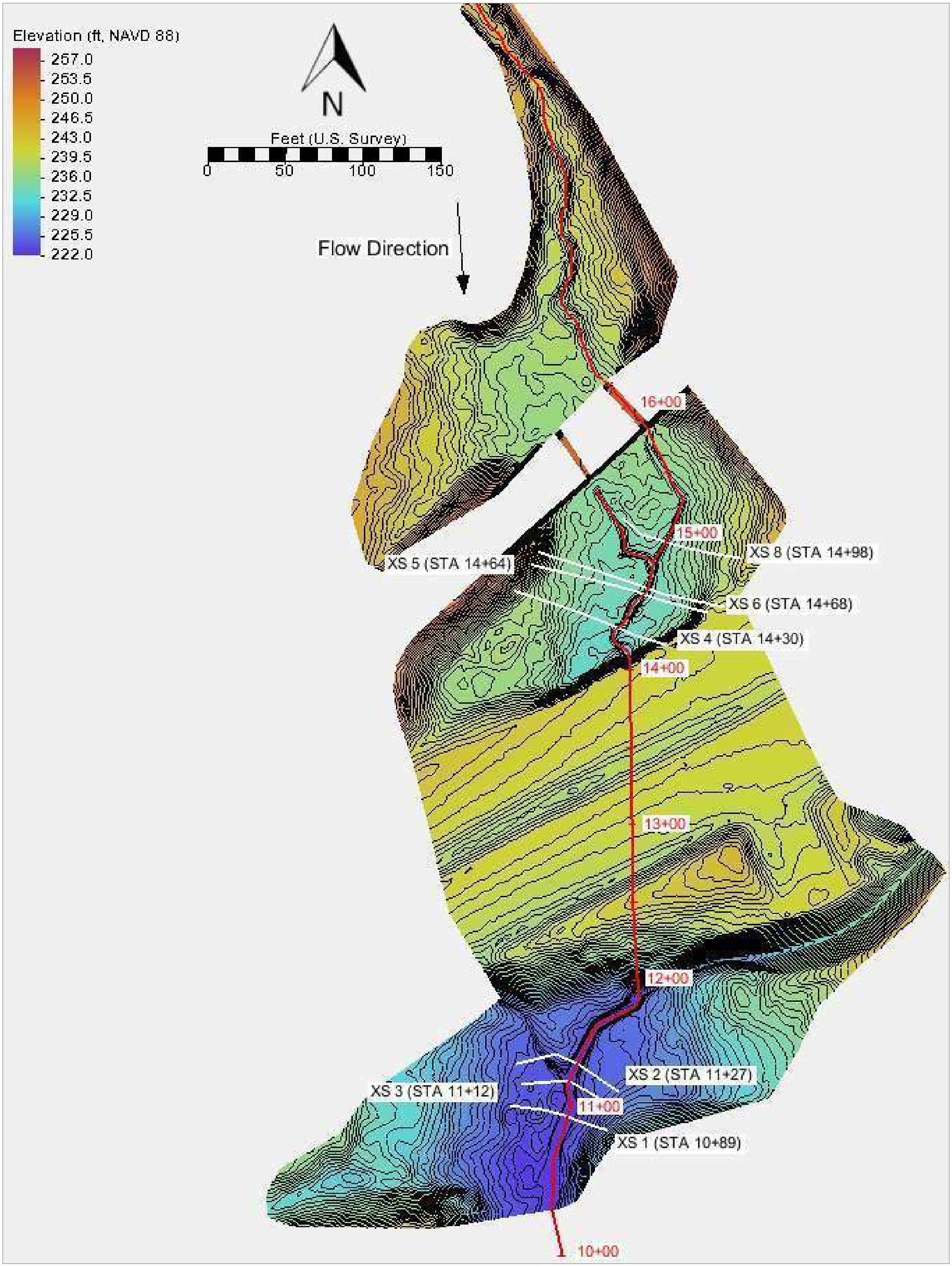
5.3 Natural Conditions

A natural-conditions model was developed since the system is unconfined with an average FUR over 3.0. See Section 2.7.2.1 for FUR calculations. Natural conditions were simulated by artificially widening the SR 3 culvert from a 36-inch-diameter culvert to a 40- by 20-foot concrete box culvert. A Manning's value of 0.012 was selected for the culvert as this is a standard value used for concrete structures. This artificial culvert was wide enough to mitigate the backwatering observed under existing conditions for the 2-year, 100-year, and 500-year MRIs. The two existing culverts under the on-ramp were left unaltered. The natural-conditions model was run for the 2-year, 100-year, and 500-year MRIs.

The average hydraulic results of the WSE, water depth, velocity, and shear stress are reported in Table 15, and the respective cross section locations are shown on Figure 51. Figure 52 and Figure 53 show the water surface profile and a typical section from the reference reach for the scenarios that were evaluated, respectively. The figures also include the existing-conditions WSEs for comparison.

The water surface profiles on Figure 52 show that, under natural conditions, the reach upstream of the SR 3 crossing is no longer under backwater conditions. WSEs decrease by approximately 5.5 feet for the 100-year MRI and 6.5 feet for the 500-year MRI. The 2-year WSE decreases slightly (0.3 feet) under natural conditions indicating that the existing crossing was under backwater conditions above STA 15+00 at the 2-year MRI. The cross section on Figure 53 shows a similar decrease in WSEs, but the channel remains connected to the floodplain at all MRIs.

Table 16 lists average main channel and floodplain velocities under natural conditions. Figure 54 and Figure 55 show the upstream and downstream velocity results in plan view, respectively. Due to the constriction of the undersized culvert being removed from the crossing, main channel average velocities and shear stress across all flows evaluated increased through the reference reach. At the 100-year MRI, upstream average main channel velocities ranged from 5.6 at Cross section 8 to 2.2 fps at Cross section 4. The decrease in velocities moving downstream is due to the channel slope flattening as it approaches the crossing. Velocities in the downstream reach remained approximately the same as existing conditions, with the highest velocities at the SR 3 culvert outlet. Floodplain inundation is shallower and slower relative to existing conditions; this is inversely related to the increase in main channel velocity for natural conditions.

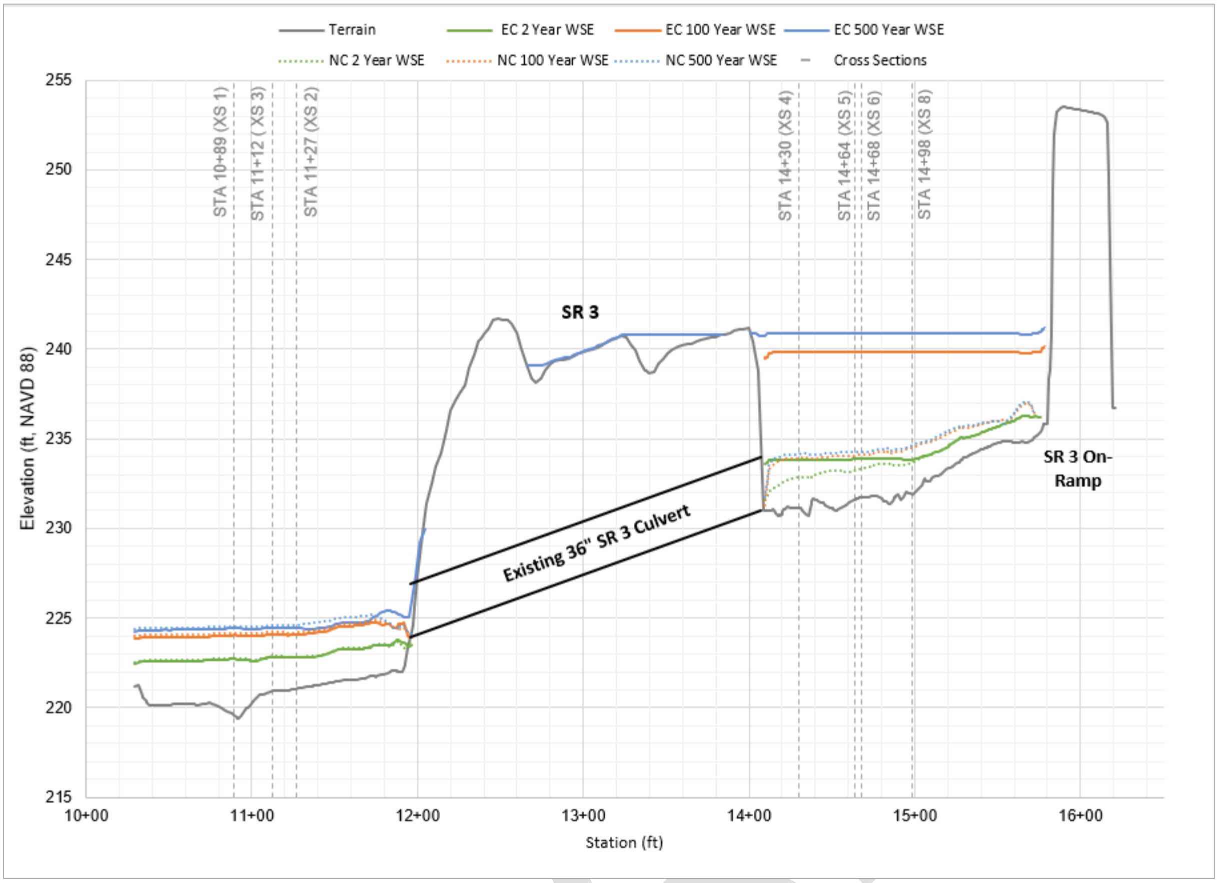


Note: Alignment is the existing alignment as shown on Sheet CE1 in Appendix D.

Figure 51: Locations of cross sections used for results reporting

Table 15: Average main channel hydraulic results for natural conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year
Average WSE (ft, NAVD 88)	XS 8 (STA E14+98)	233.7	234.5	234.7
	XS 6 (STA E14+68)	233.3	234.1	234.3
	XS 5 (STA E14+64)	233.2	234.1	234.3
	XS 4 (STA E14+30)	232.9	233.9	234.2
	Structure	NA	NA	NA
	XS 2 (STA E11+27)	222.8	224.2	224.6
	XS 3 (STA E11+12)	222.9	224.2	224.7
	XS 1 (STA E10+89)	222.7	224.2	224.6
Max depth (ft)	XS 8 (STA E14+98)	1.8	2.6	2.7
	XS 6 (STA E14+68)	1.6	2.4	2.6
	XS 5 (STA E14+64)	1.7	2.6	2.8
	XS 4 (STA E14+30)	2.1	3.1	3.3
	Structure	NA	NA	NA
	XS 2 (STA E11+27)	1.8	3.1	3.6
	XS 3 (STA E11+12)	2.0	3.3	3.7
	XS 1 (STA E10+89)	3.4	4.8	5.2
Average velocity (fps)	XS 8 (STA E14+98)	5.1	5.6	5.7
	XS 6 (STA E14+68)	3.9	3.9	3.8
	XS 5 (STA E14+64)	3.8	3.5	3.3
	XS 4 (STA E14+30)	2.6	2.2	2.1
	Structure	NA	NA	NA
	XS 2 (STA E11+27)	0.6	4.8	4.5
	XS 3 (STA E11+12)	0.2	3.0	2.9
	XS 1 (STA E10+89)	0.1	1.7	1.7
Average shear (lb/SF)	XS 8 (STA E14+98)	1.6	1.6	1.7
	XS 6 (STA E14+68)	0.8	0.7	0.6
	XS 5 (STA E14+64)	0.7	0.5	0.4
	XS 4 (STA E14+30)	0.4	0.2	0.2
	Structure	NA	NA	NA
	XS 2 (STA E11+27)	0.6	0.9	0.7
	XS 3 (STA E11+12)	0.2	0.4	0.4
	XS 1 (STA E10+89)	0.1	0.3	0.3



Note: Alignment is the existing alignment as shown on Sheet CE1 in Appendix D.

Figure 52: Existing-conditions (EC) and Natural Conditions (NC) water surface profiles

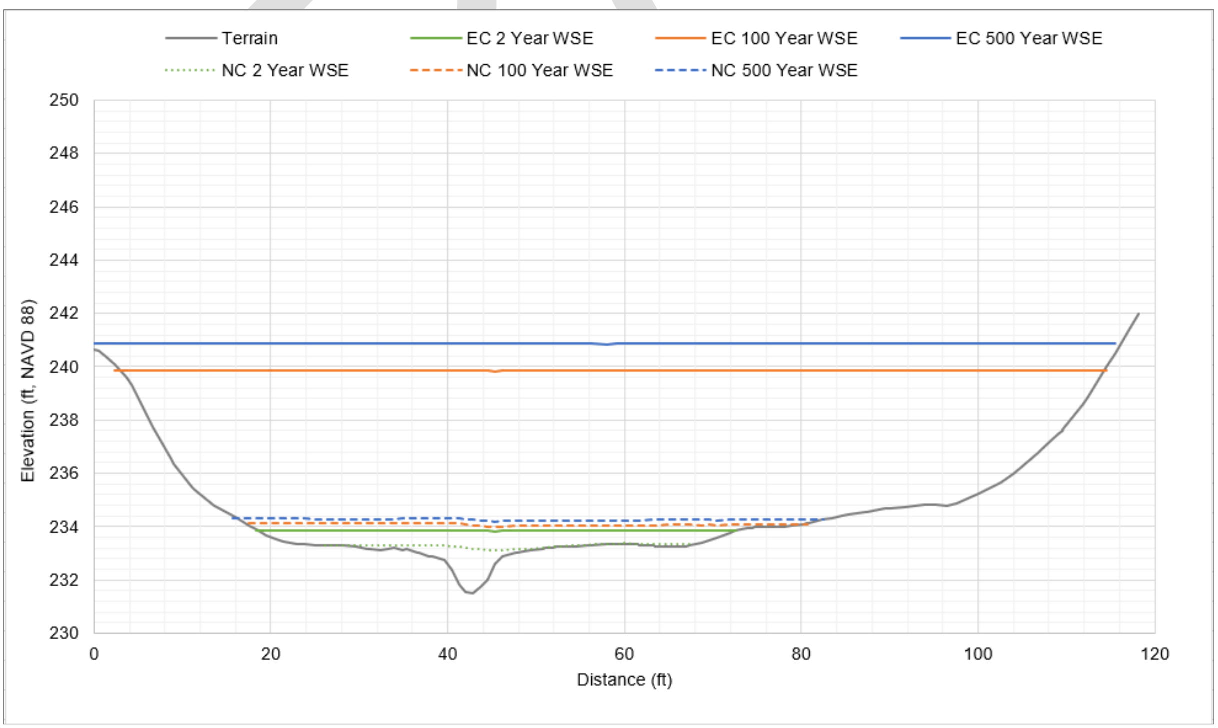
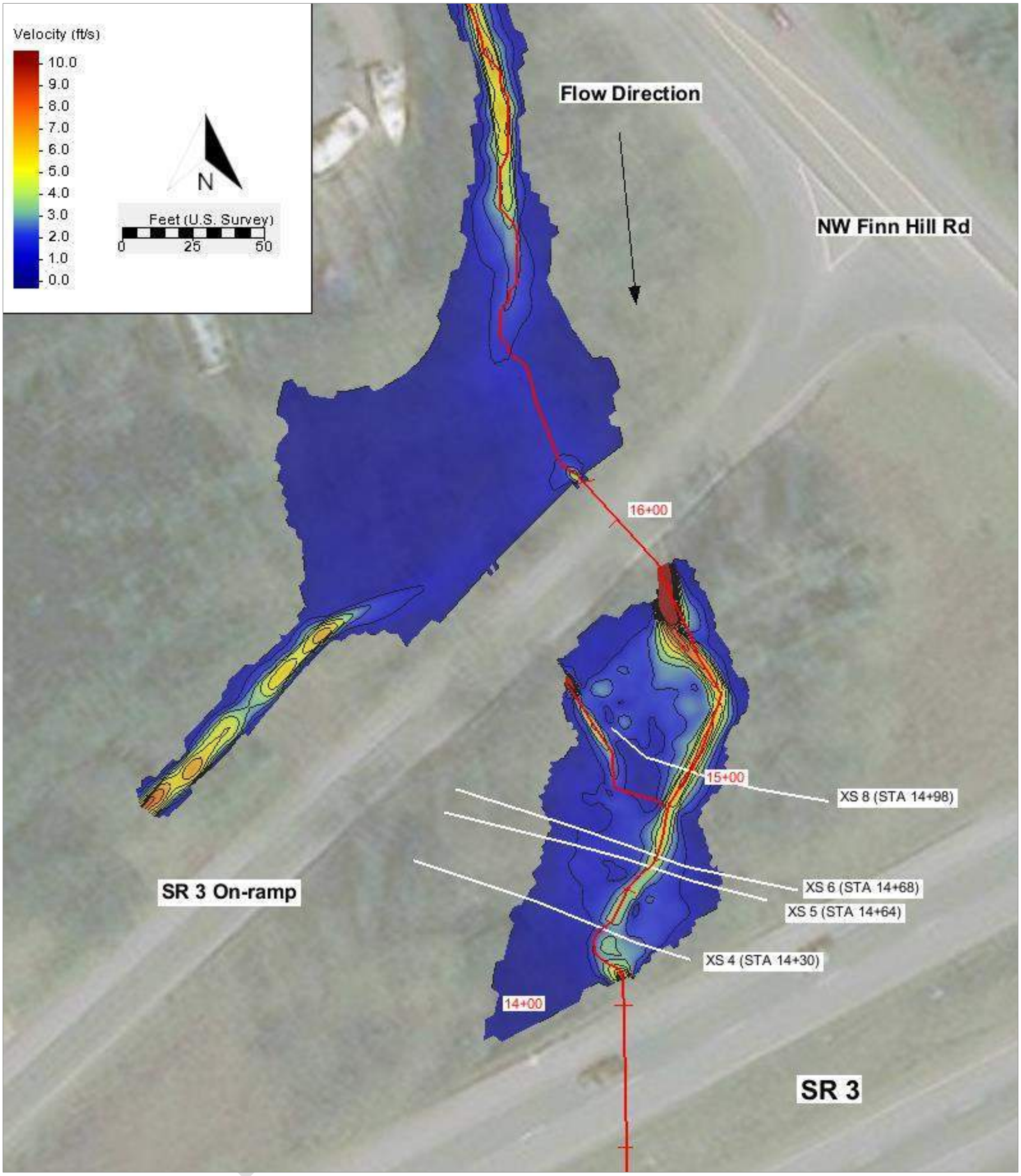
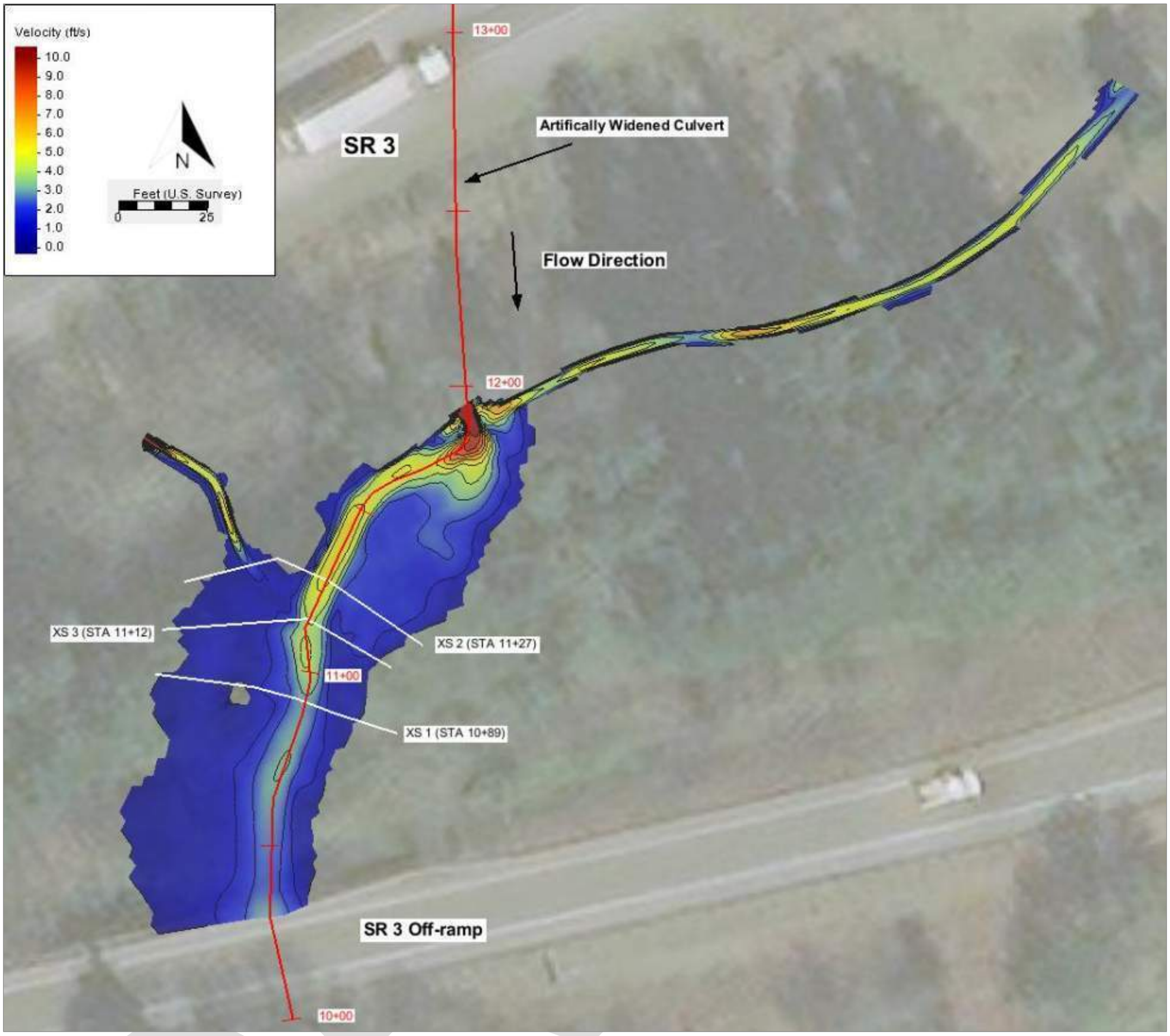


Figure 53: Typical upstream existing channel cross section (STA 14+64)



Note: Alignment is the existing alignment as shown on Sheet CE1 in Appendix D.

Figure 54: Natural-conditions upstream reach 100-year velocity map with cross section locations



Note: Alignment is the existing alignment as shown on Sheet CE1 in Appendix D.

Figure 55: Natural-conditions downstream reach 100-year velocity map with cross section locations

Table 16: Natural-conditions average channel and floodplains velocities

Cross section location	Q100 average velocities tributary scenario (fps)		
	LOB[a]	Main channel	ROB[a]
XS 8 (STA E14+98)	1.3	5.6	1.9
XS 6 (STA E14+68)	1.1	3.9	1.0
XS 5 (STA E14+64)	1.1	3.5	1.0
XS 4 (STA E14+30)	0.6	2.2	2.1
Structure	NA	NA	NA
XS 2 (STA E11+27)	0.8	4.8	1.4
XS 3 (STA E11+12)	0.8	4.8	1.4
XS 1 (STA E10+89)	0.7	3.0	0.9

a. ROB/LOB locations were approximated based on inspection of topographic breaks upstream of the crossing and based on the 2-year event water surface top widths downstream of the crossing.

5.4 Proposed Conditions: 20-Foot Minimum Hydraulic Width

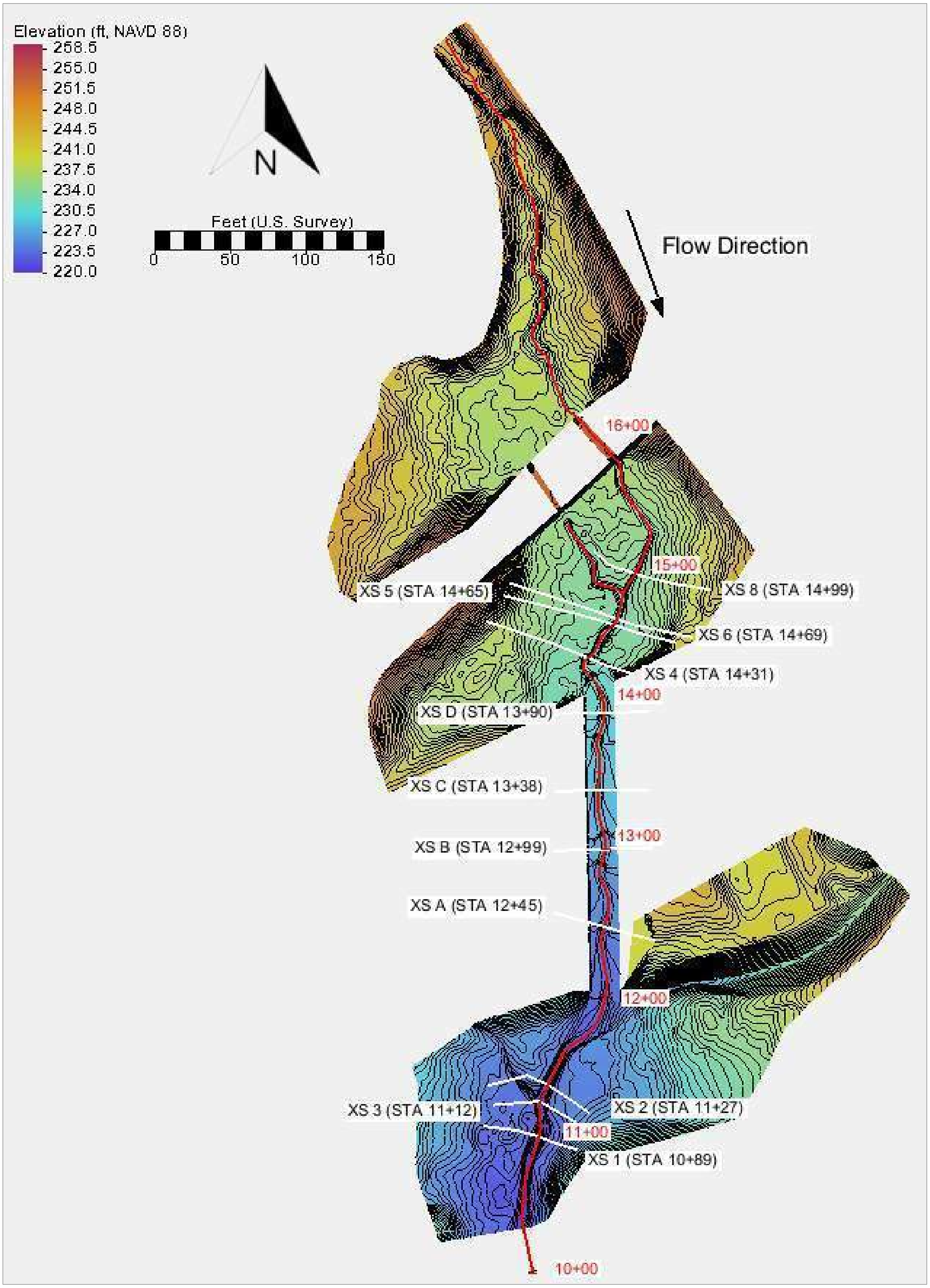
The hydraulic width is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic modeling assumes vertical walls at the edge of the minimum hydraulic width unless otherwise specified. See Section 4.2.2 for a description of how the minimum hydraulic width was determined.

The proposed-conditions model provided results for the 2-year; 100-year; 500-year; and projected 2080, 100-year MRIs. The proposed glide step-pool design includes five pools within the structure and an additional pool at the entrance and exit of the structure. These steps separating glides are visible on Figure 57 and Figure 58. The evident backwater of water surface elevation at the downstream end of the proposed crossing (Figure 57) is due to the influence of the SR 3 off-ramp culvert crossing (not shown on this figure). Figure 56 shows the cross section locations where model results were tabulated, and Table 17 shows the average WSE, depth, velocity, and shear stress results for the MRIs listed above. Cross sections A through D are located within the proposed crossing. Cross section D is located at the top of a step, Cross sections C and B are in glide sections, and Cross section A is through a typical pool.

The proposed step-pool design performs similar to the observed glide-pool morphology in the reference reach in regard to velocity distribution and depth, shown on Figure 58. Model results indicate 100-year velocities along the thalweg ranging from 2.7 fps to 5.9 fps in the pool and 6.7 fps to 8.8 fps over the step. Natural condition, 100-year velocities in the reference reach thalweg range from 4.4 fps to 8.0 fps. Therefore, the maximum velocities through the proposed channel fall within 9 percent of the maximum velocities in the reference reach. Other average main channel hydraulic metrics at Cross sections A through D (Figure 33), shown in Table 17, are within the range of natural-condition results in the reference reach at Cross section 5 (Existing STA 14+64), Cross section 6 (Existing STA 14+68), and Cross section 8 (Existing STA 14+98).

The WSE of a typical riffle section through the crossing is shown on Figure 59. The spatial distribution of velocity at the 100-year event is shown in plan view on Figure 60, Figure 61, and Figure 62 and tabulated in Table 18. Figure 60, Figure 61, and Figure 62 show generally higher velocities in the crossing than either upstream or downstream.

The crossing terrain incorporates each step in the step pool-glide morphology. Each modeled step is near vertical and generates significant velocity in the model results, though this effect is localized. The glides (treads) separating each step are at a slope of either 1.5 or 2 percent. These gradients are within the range of the observed upstream reach slope (3.1 percent) and downstream reach slope (1.2 percent); however, the model tends to enhance the effect of these steps. Additionally, though this morphology of step-pool tread was observed in the reference reach, this morphology is not well captured in the survey and tends to over smooth the observed steps. Consequently, the hydraulic conditions in the crossing appear different from either the upstream or downstream reaches. Table 18 shows 100-year velocities for the main channel and overbanks; overbank velocities in excess of 3 fps correspond to cross sections on the steep lee side of the meander bars. Cross section D STA P13+90 shows the highest hydraulic results through the structure; this is due to being located directly at a step.

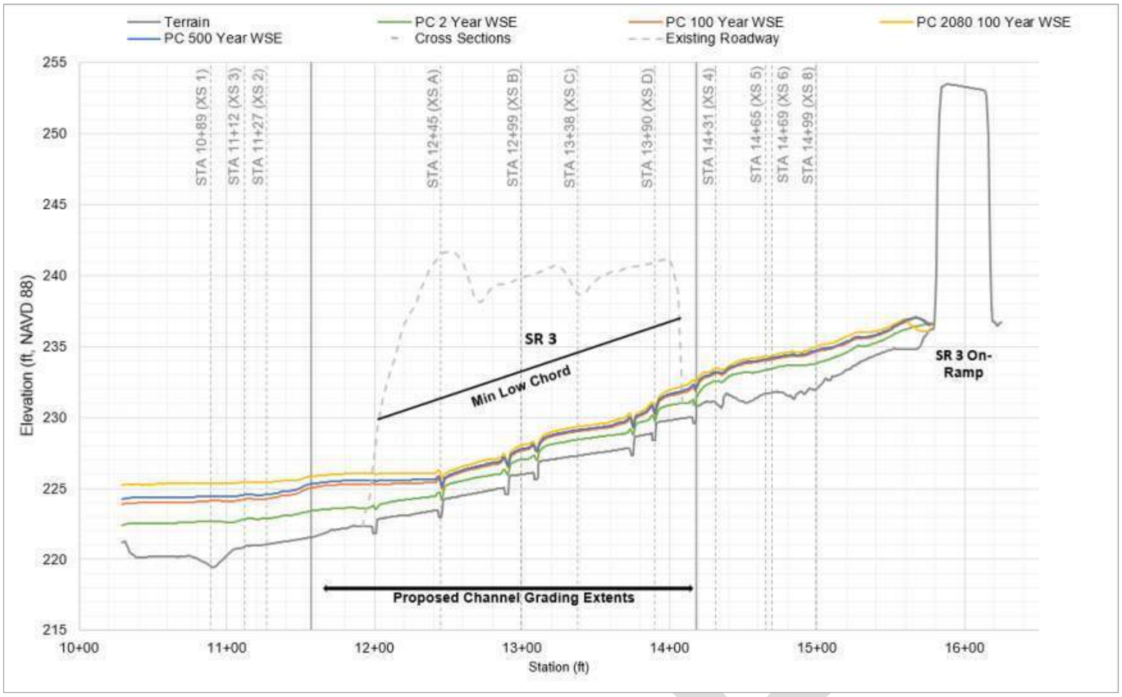


Note: Alignment is the proposed alignment as shown on Sheet CR1 in Appendix D.

Figure 56: Locations of cross sections on proposed alignment used for results reporting

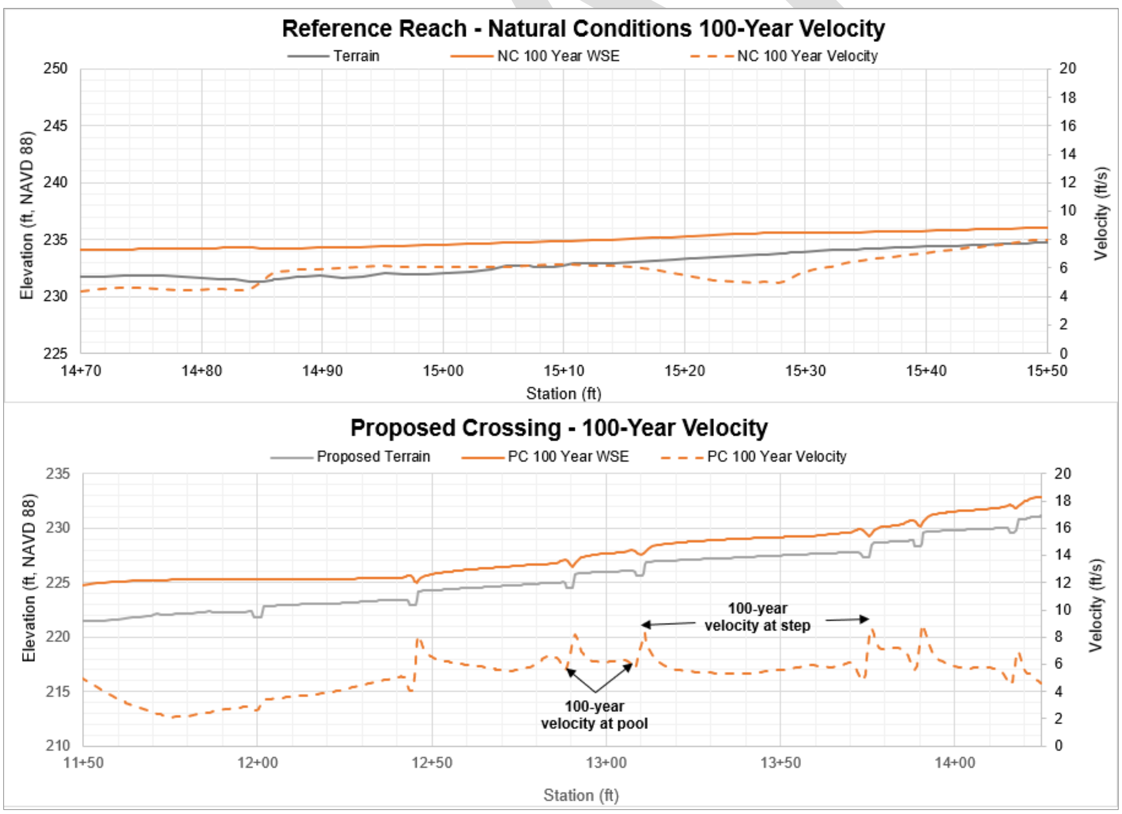
Table 17: Average main channel hydraulic results for proposed conditions

Hydraulic parameter	Cross section	2-year	100-year	Projected 2080, 100-year	500-year
Average WSE (ft, NAVD 88)	XS 8 (STA P14+99)	233.8	234.6	234.9	234.7
	XS 6 (STA P14+69)	233.4	234.0	234.3	234.1
	XS 5 (STA P14+65)	233.2	233.9	234.2	234.0
	XS 4 (STA P14+31)	232.6	233.1	233.4	233.2
	XS D (STA P13+90)	230.1	230.5	230.9	230.6
	XS C (STA P13+38)	228.5	229.0	229.4	229.2
	XS B (STA P12+99)	227.0	227.7	228.0	227.8
	XS A (STA P12+45)	224.6	225.5	226.2	225.7
	XS 2 (STA P11+27)	222.9	224.3	225.4	224.6
	XS 3 (STA P11+12)	222.9	224.3	225.4	224.6
	XS 1 (STA P10+89)	222.7	224.1	225.4	224.5
Max depth (ft)	XS 8 (STA P14+99)	1.9	2.7	3.0	2.8
	XS 6 (STA P14+69)	1.7	2.3	2.6	2.4
	XS 5 (STA P14+65)	1.7	2.4	2.7	2.5
	XS 4 (STA P14+31)	1.8	2.4	2.7	2.5
	XS D (STA P13+90)	1.1	1.5	1.8	1.6
	XS C (STA P13+38)	1.1	1.7	2.1	1.8
	XS B (STA P12+99)	1.1	1.7	2.1	1.8
	XS A (STA P12+45)	1.8	2.7	3.3	2.9
	XS 2 (STA P11+27)	1.8	3.2	4.4	3.5
	XS 3 (STA P11+12)	2.0	3.4	4.6	3.7
	XS 1 (STA P10+89)	3.3	4.8	6.0	5.1
Average velocity (fps)	XS 8 (STA P14+99)	3.9	3.9	4.1	4.0
	XS 6 (STA P14+69)	3.4	3.6	3.8	3.7
	XS 5 (STA P14+65)	3.4	3.4	3.5	3.4
	XS 4 (STA P14+31)	3.3	4.1	4.3	4.1
	XS D (STA P13+90)	6.0	8.2	9.1	8.5
	XS C (STA P13+38)	3.5	5.1	6.0	5.4
	XS B (STA P12+99)	4.0	5.8	6.6	6.1
	XS A (STA P12+45)	3.5	4.4	4.6	4.4
	XS 2 (STA P11+27)	2.8	4.5	3.6	4.5
	XS 3 (STA P11+12)	3.9	2.9	2.4	2.9
	XS 1 (STA P10+89)	3.4	1.6	1.5	1.6
Average shear (lb/SF)	XS 8 (STA P14+99)	1.0	0.9	1.0	0.9
	XS 6 (STA P14+69)	0.6	0.6	0.6	0.6
	XS 5 (STA P14+65)	0.6	0.5	0.5	0.5
	XS 4 (STA P14+31)	0.7	0.8	0.8	0.8
	XS D (STA P13+90)	4.5	6.5	7.4	6.8
	XS C (STA P13+38)	0.7	1.3	1.7	1.4
	XS B (STA P12+99)	1.0	1.7	2.1	1.8
	XS A (STA P12+45)	1.3	1.5	1.4	1.4
	XS 2 (STA P11+27)	0.5	0.8	0.4	0.8
	XS 3 (STA P11+12)	0.2	0.4	0.2	0.3
	XS 1 (STA P10+89)	0.1	0.2	0.2	0.2
Average grain stress (lb/SF)	XS 8 (STA P14+99)	0.6	0.6	0.6	0.6
	XS 6 (STA P14+69)	0.5	0.5	0.5	0.5
	XS 5 (STA P14+65)	0.5	0.4	0.5	0.5
	XS 4 (STA P14+31)	0.5	0.6	0.7	0.6
	XS D (STA P13+90)	1.1	1.7	2.0	1.8
	XS C (STA P13+38)	0.5	0.8	1.1	0.9
	XS B (STA P12+99)	0.6	1.0	1.2	1.1
	XS A (STA P12+45)	0.5	0.7	0.7	0.7
	XS 2 (STA P11+27)	0.4	0.7	0.5	0.7
	XS 3 (STA P11+12)	0.2	0.4	0.3	0.4
	XS 1 (STA P10+89)	0.1	0.2	0.1	0.2



Note: Alignment is the proposed alignment as shown on Sheet CR1 in Appendix D.

Figure 57: Proposed-conditions water surface profiles



Note: Alignments are the proposed alignment as shown on Sheet CR1 in Appendix D and the existing alignment as shown on Sheet CE1 in Appendix D.

Figure 58: Proposed crossing 100-year water surface profile and velocity compared to reference reach 100-year water surface profiles and velocity

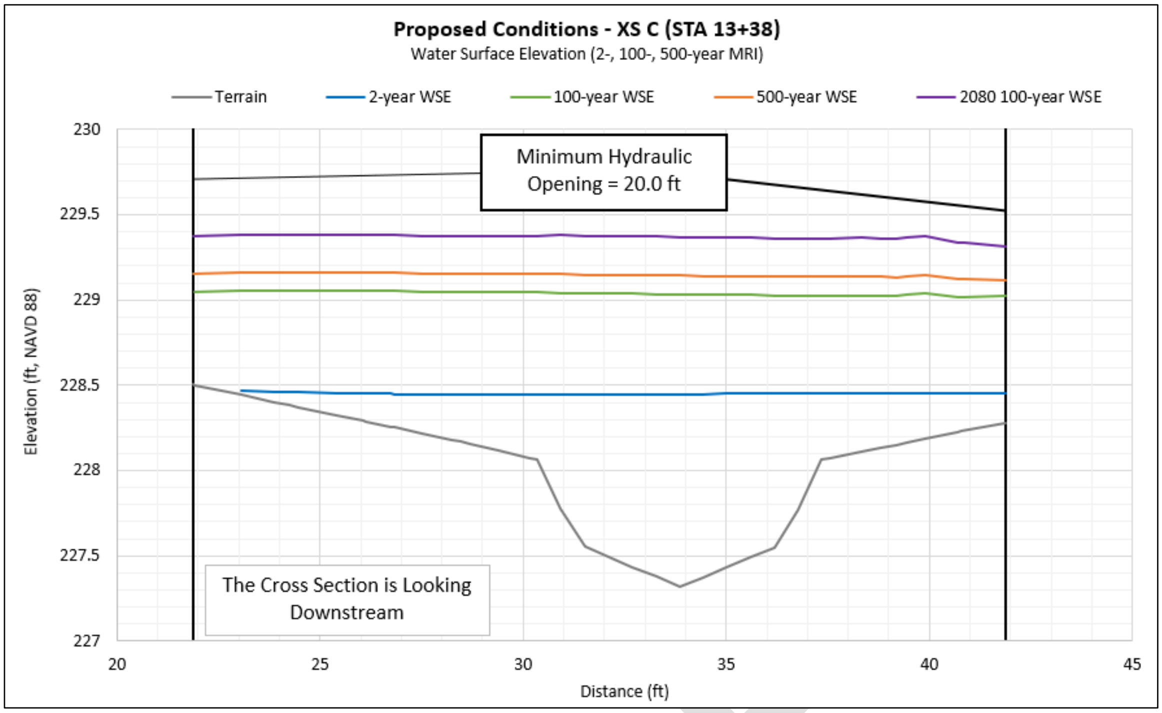
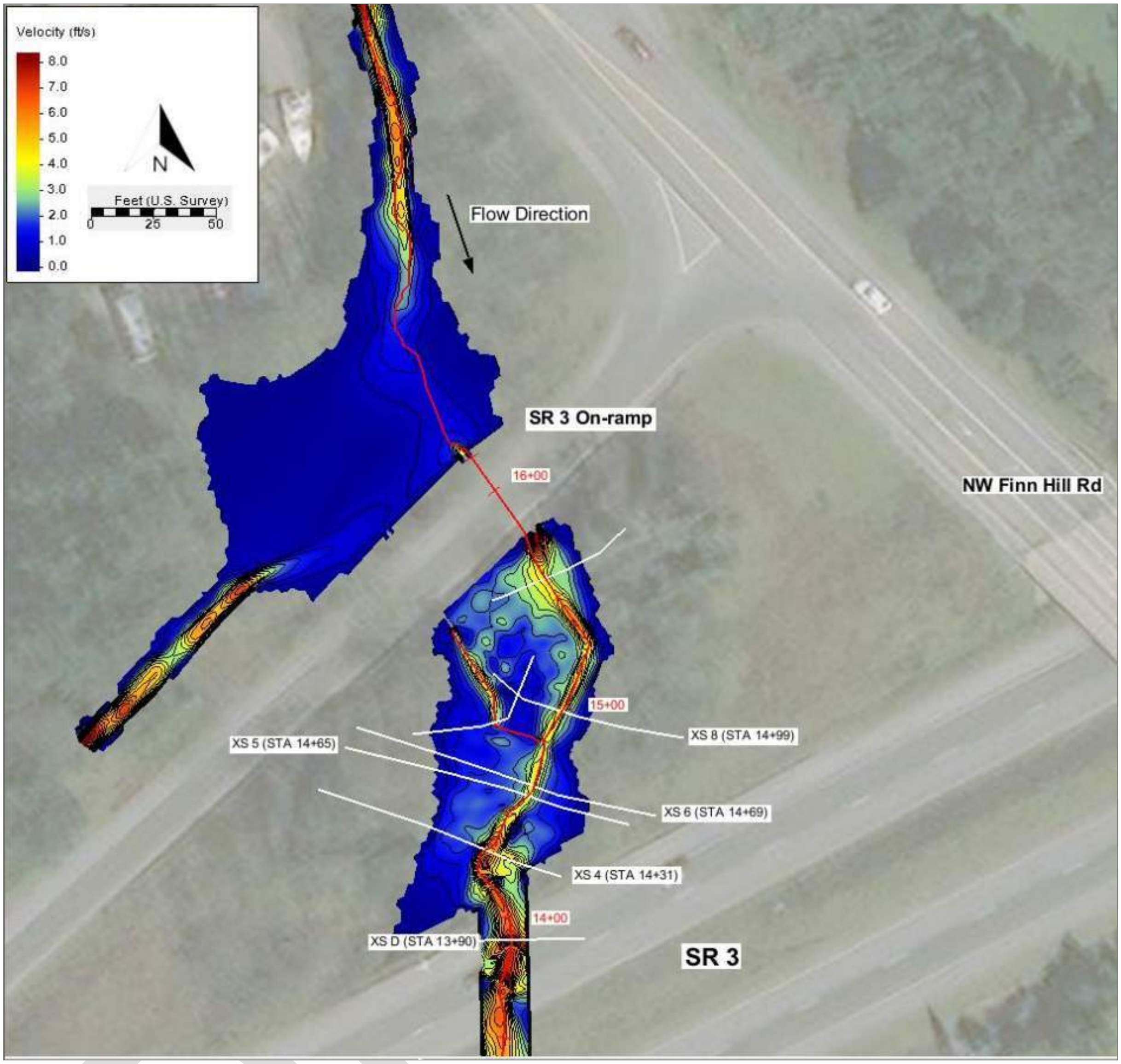
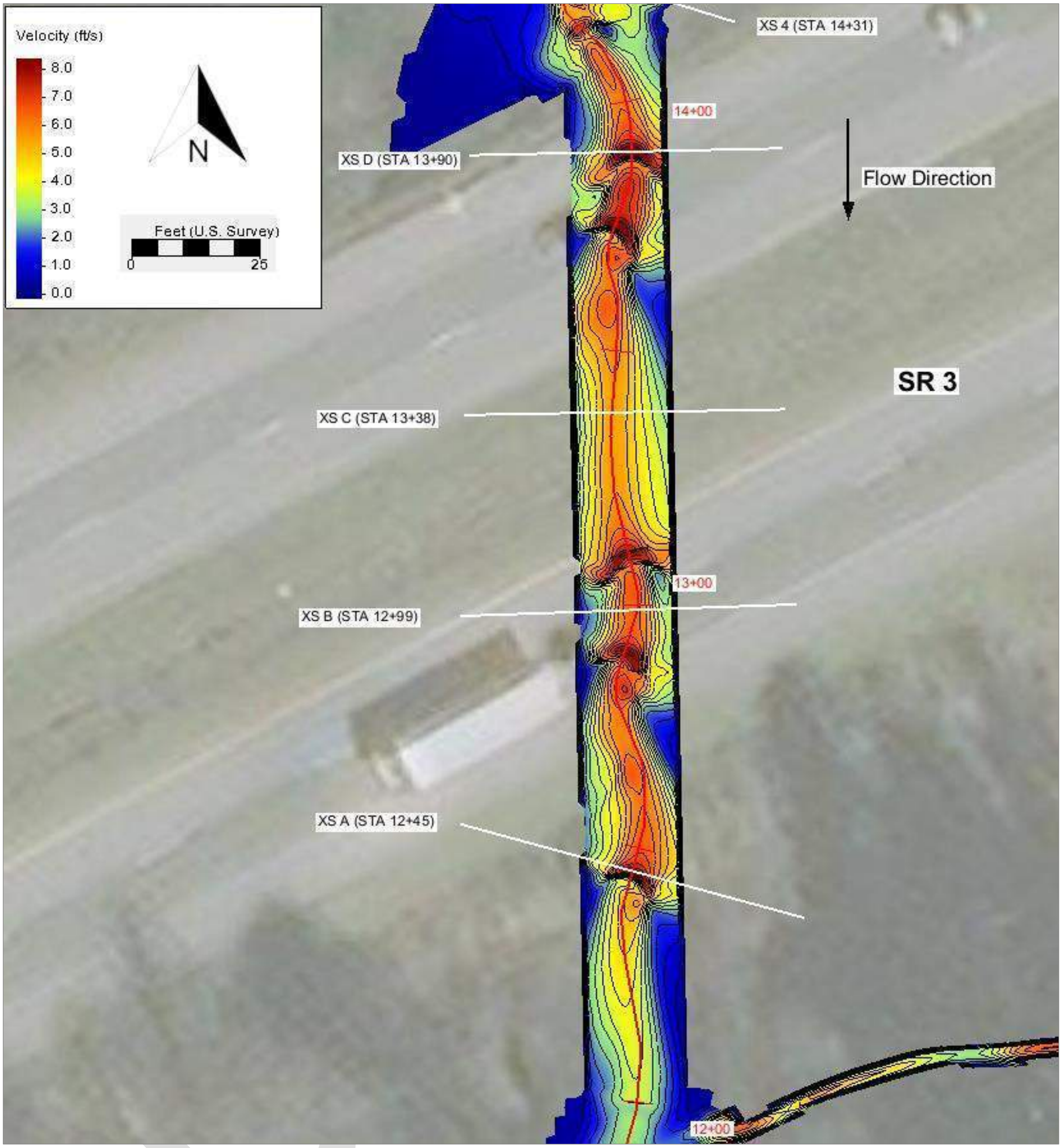


Figure 59: Typical section through proposed structure (STA P13+38)



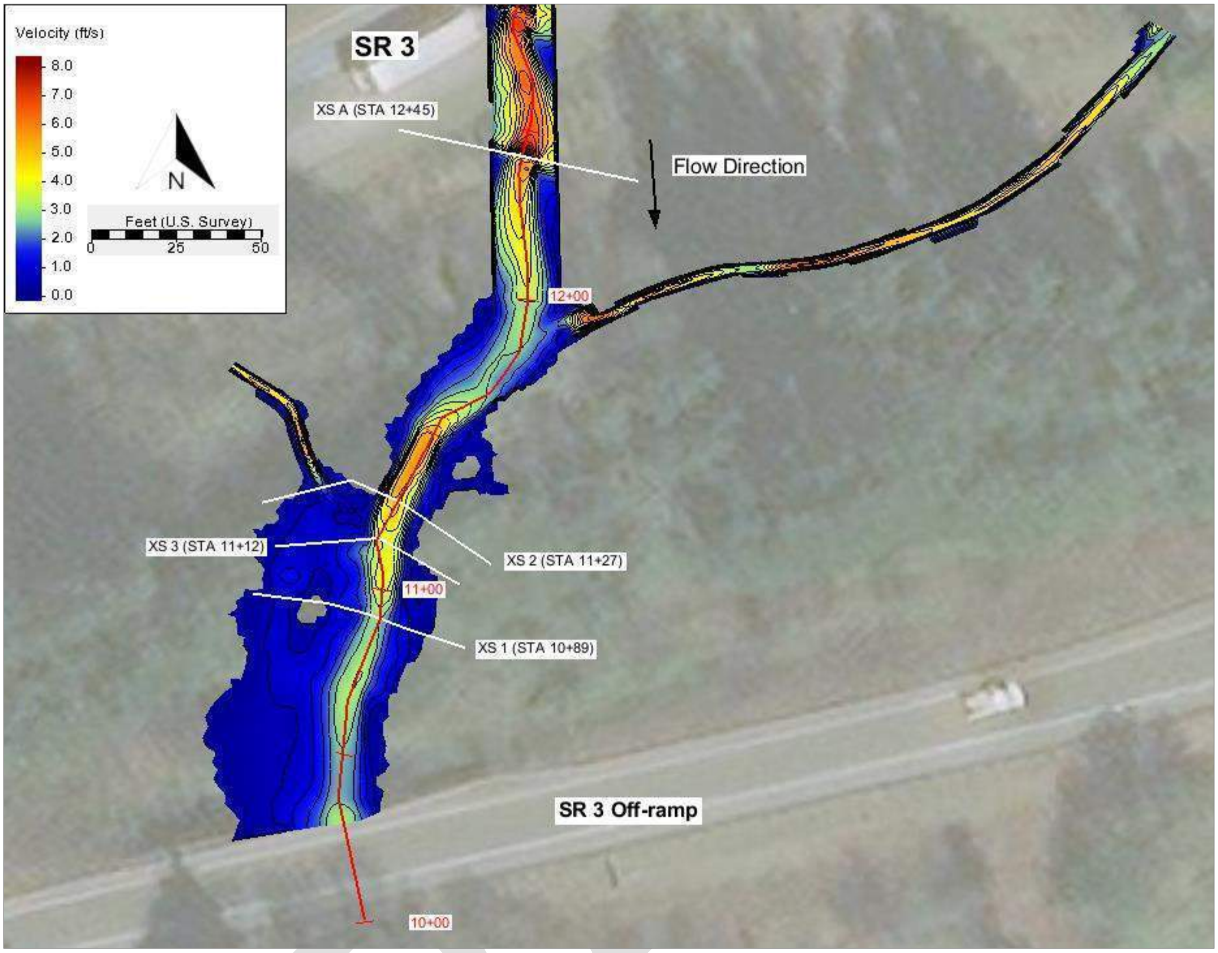
Note: Alignment is the proposed alignment as shown on Sheet CR1 in Appendix D.

Figure 60: Proposed-conditions 100-year velocity map, upstream reach



Note: Alignment is the proposed alignment as shown on Sheet CR1 in Appendix D.

Figure 61: Proposed-conditions 100-year velocity map, proposed crossing



Note: Alignment is the proposed alignment as shown on Sheet CR1 in Appendix D.

Figure 62: Proposed-conditions 100-year velocity map, downstream reach

Table 18: Proposed-conditions average channel and floodplains velocities

Cross section location	Q100 average velocities (fps)			2080 Q100 average velocity (fps)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
XS 8 (STA P14+99)	1.3	3.9	1.4	1.7	4.1	1.7
XS 6 (STA P14+69)	1.4	3.6	1.1	1.8	3.8	1.3
XS 5 (STA P14+65)	1.4	3.4	1.2	1.9	3.5	1.3
XS 4 (STA P14+31)	1.4	4.1	3.7	1.8	4.3	4.1
XS D (STA P13+90)	4.0	8.2	5.1	4.9	9.1	6.1
XS C (STA P13+38)	3.0	5.1	3.4	4.2	6.0	4.1
XS B (STA P12+99)	2.8	5.8	2.8	3.7	6.6	3.8
XS A (STA P12+45)	2.0	4.4	4.4	2.1	4.6	4.9
XS 2 (STA P11+27)	0.9	4.5	1.3	0.7	3.6	1.2
XS 3 (STA P11+12)	0.8	2.9	1.0	1.0	2.4	1.1
XS 1 (STA P10+89)	0.5	1.6	0.1	0.9	1.5	0.1

a. ROB/LOB locations were approximated based on inspection of topographic breaks upstream of the crossing and based on the 2-year event water surface top widths downstream of the crossing.

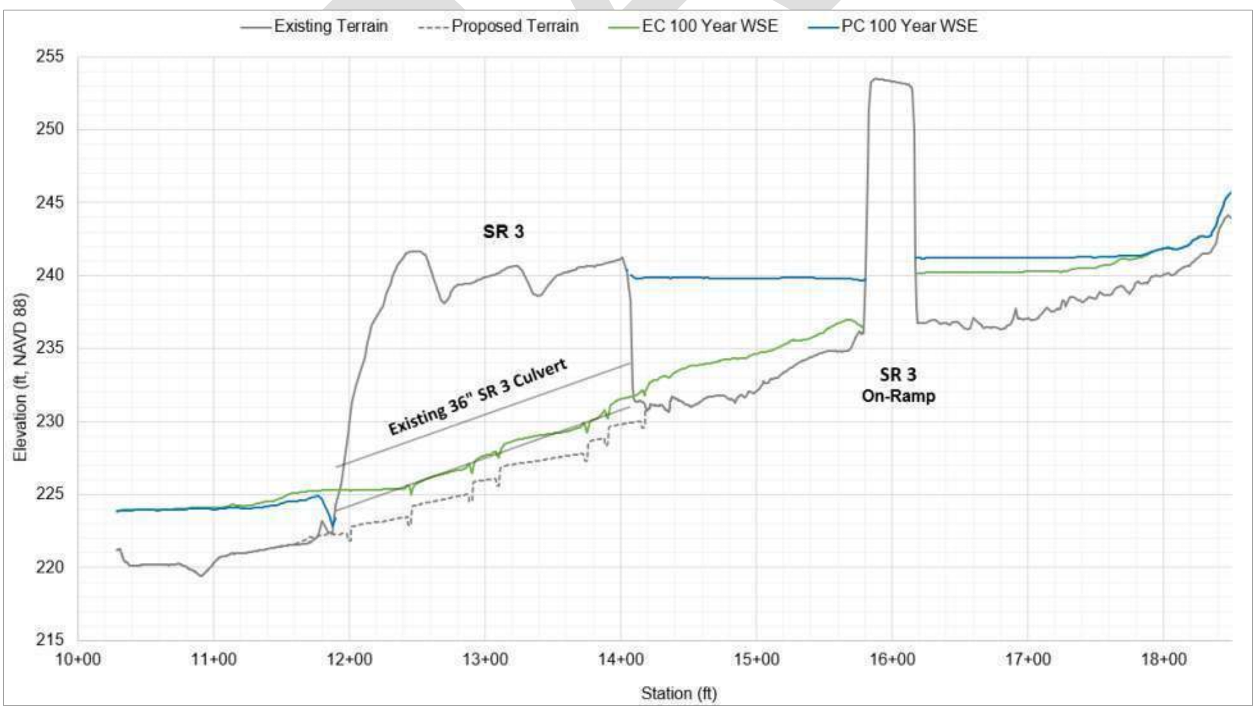
6 Floodplain Evaluation

As noted in Section 2.1, this project is not within a FEMA special flood hazard area. The area is designated as Zone X-area of minimal flood hazard (FEMA 2017). See Appendix A for FIRMette. The existing-project and expected proposed-project conditions were evaluated to determine whether the project would cause a change in flood risk.

6.1 Water Surface Elevations

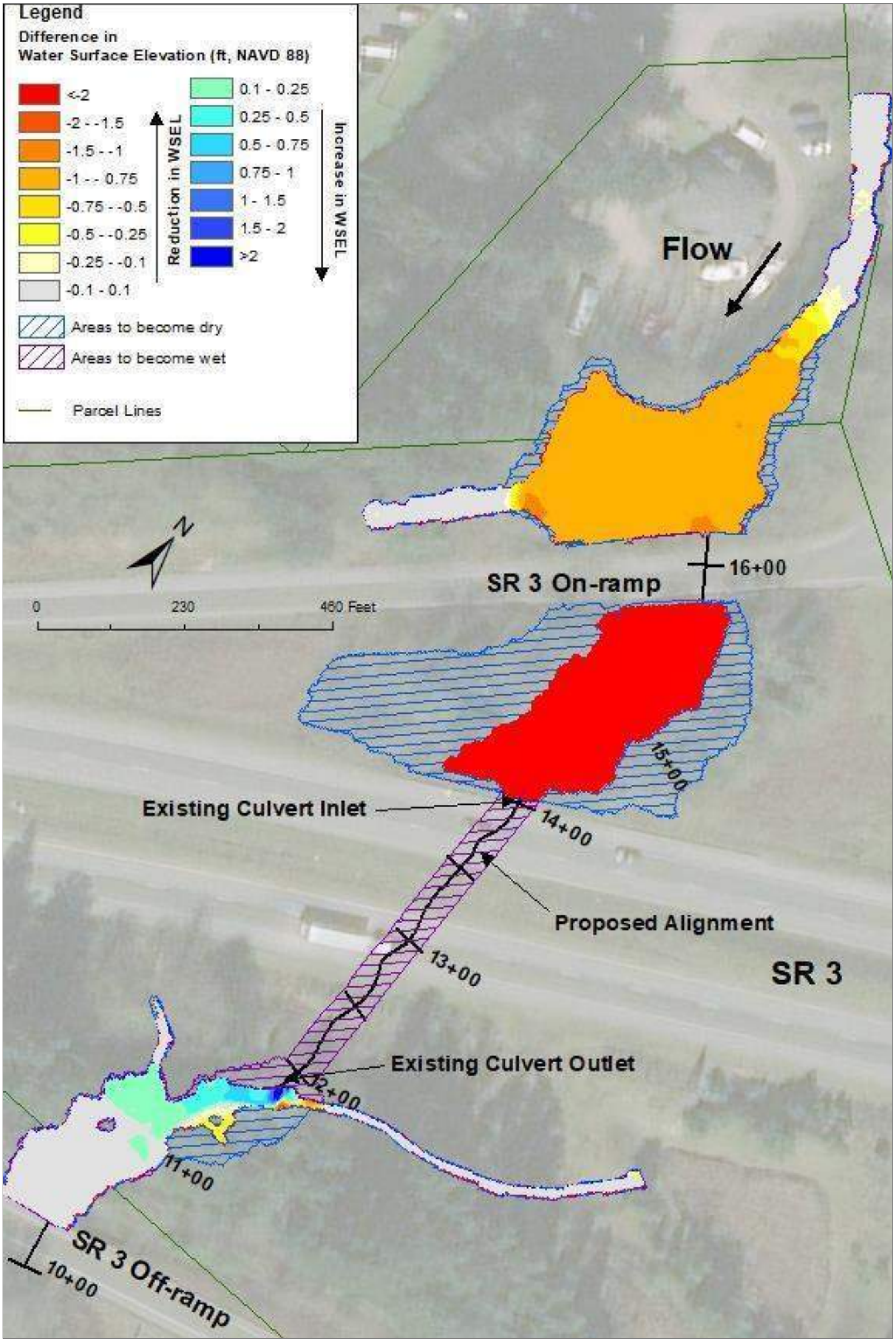
Generally, WSEs decrease across the model domain when comparing the existing and proposed conditions. Figure 63 shows the water surface profile comparing the 100-year MRI results for existing and proposed conditions. The proposed crossing eliminates the backwatering of the reach upstream of the SR 3 culvert and decreases the 100-year MRI WSE by up to 6 feet at the existing culvert inlet.

Figure 64 shows a comparison of the existing and proposed model results at the 100-year MRI. This figure shows that the proposed crossing decreases flooding upstream of the proposed crossing by decreasing WSEs. There is a small area of local WSE rise downstream of the crossing. The largest increase is approximately 2.3 feet at the outlet of the existing culvert but rises beyond of the first 10 feet from the outlet are less than 1 foot. These increases are likely due to increased conveyance through the crossing and do not pose a risk to properties or infrastructure due to their localized nature. A flood risk assessment will be developed during later stages of the design.



Note: Alignment is the proposed alignment as shown on Sheet CR1 in Appendix D.

Figure 63: Existing- and proposed-conditions 100-year water surface profile comparison along proposed alignment



Note: Alignment is the proposed alignment as shown on Sheet CR1 in Appendix D.

Figure 64: 100-year WSE change from existing to proposed conditions

7 Scour Analysis

Total scour will be computed during later phases of the project using flows up to the 100-year; 500-year; and projected 2080, 100-year flow events. The proposed structure will be designed to account for the potential scour at the projected 2080, 100-year flow event. For this preliminary phase of the project, the risk for lateral migration and potential for degradation are evaluated on a conceptual level. This information is considered preliminary and is not to be taken as a final recommendation in either case. The geotechnical scoping memorandum from the WSDOT Geotechnical Office was not available as this PHD was prepared; upon receiving this input, a separate scour memorandum will be created to inform the scour free zone.

7.1 Lateral Migration

The risk of lateral migration upstream of the crossing is moderate. The channel upstream of the crossing has relatively low banks and the adjacent floodplain shows signs of frequent inundation. Accumulations of organic debris (leaf litter and small woody material) were observed to cause minor changes in channel alignment. However, the channel banks and adjacent floodplain are composed of highly cohesive sediment that resists channel migration. Lateral migration appears most likely the result of avulsion (sudden channel change) rather than the result of bank erosion. The upstream riparian area is composed entirely of deciduous trees and shrubs. During autumn, leaf fall can create significant accumulations of organic debris in or at the margin of the active channel. When these accumulations are augmented by random small woody material (such as tree branches), the channel can be diverted around these obstructions to create a new flow path, and over time, if the flow path is frequently engaged, a new stream channel. This process was observed in between the crossing and the upstream on-ramp crossing. This means of lateral migration is more random that predictable and the erodibility of banks does not present a contributing factor. Other factors, such as low channel banks and frequent floodplain inundation, are attenuated in the design. Additional factors that typically contribute to lateral migration, such as high sediment supply, are not significant at this crossing.

7.2 Long-term Degradation of the Channel Bed

There is potential for degradation followed by aggradation at the crossing. As noted in Section 2.7.4, the downstream reach is incised and the upstream reach is tightly connected to the floodplain, likely due to the current crossing acting as a grade control and preventing channel regrade from progressing upstream. Assuming no grade control at the crossing, the downstream incision is likely to migrate upstream, causing degradation. The eroded material is transported downstream but we cannot predict if this material may cause aggradation to the downstream channel or merely become part of the transported sediment load. If the eroded material exceeds the transport capacity of the channel, aggradation will occur. A potential aggradation depth of up to 2 feet may occur (Figure 65). This risk of aggradation and degradation is expected to be limited to the reach between the SR 3 on- and off-ramps.

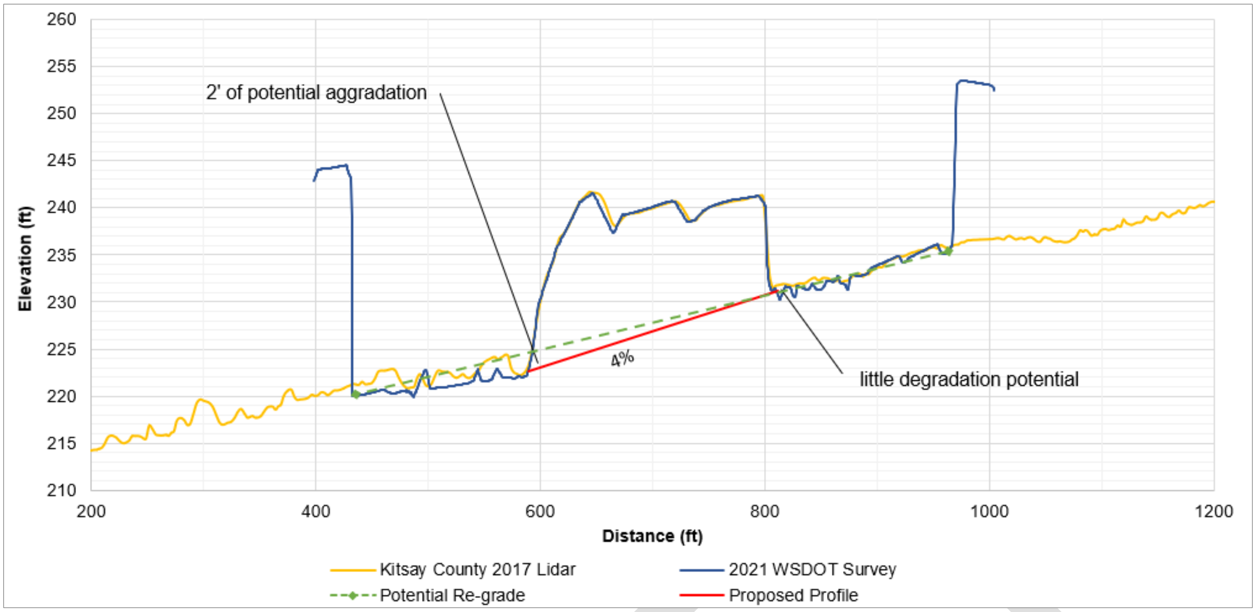


Figure 65: Potential long-term aggradation at the proposed structure upstream face

8 Scour Countermeasures

The need for scour countermeasures has not yet been determined. If scour countermeasures are needed, they will not encroach within the minimum hydraulic opening.

9 Summary

Table 19 presents a summary of the results of this PHD report.

Table 19: Report summary

Stream crossing category	Element	Value	Report location
Habitat gain	Total length	3,445 LF	2.1 Site Description
Bankfull width	Reference reach found?	Yes	2.7.1 Reference Reach Selection
	Design BFW	7.5 ft	2.7.2 Channel Geometry
	Concurrence BFW	7.5 ft	2.7.2 Channel Geometry
Floodplain utilization ratio (FUR)	Flood-prone width	57.2 ft	2.7.2.1 Floodplain Utilization Ratio
	Average FUR	14.3	2.7.2.1 Floodplain Utilization Ratio
Channel morphology	Existing	Step-pool	2.7.2 Channel Geometry
	Proposed	Step-pool	4.3.2 Channel Complexity
Hydrology/design flows	100 yr flow	88 cfs	3 Hydrology and Peak Flow Estimates
	2080, 100 yr flow	141 cfs	3 Hydrology and Peak Flow Estimates
	2080, 100 yr used for design	Yes - Freeboard	3 Hydrology and Peak Flow Estimates
	Dry channel in summer	No	3 Hydrology and Peak Flow Estimates
Channel geometry	Existing	See Figure 23	2.7.2 Channel Geometry
	Proposed	See Figure 29	4.1.1 Channel Planform and Shape
Channel slope/gradient	Existing culvert	3.4%	2.6.2 Existing Conditions
	Reference reach	3.1%	2.7.1 Reference Reach Selection
	Proposed	3.6%	4.1.3 Channel Gradient
Hydraulic width	Existing	3 ft	2.6.2 Existing Conditions
	Proposed	20 ft	4.2.2 Hydraulic Width
	Added for climate resilience	No	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	3 ft	4.2.3 Vertical Clearance
	Required freeboard applied to 100 yr or 2080, 100 yr	2080, 100 yr	4.2.3 Vertical Clearance
	Maintenance clearance	Recommended - 6 ft	4.2.3 Vertical Clearance
	Low chord elevation	See Table 9	4.2.3 Vertical Clearance
Crossing length	Existing	211 ft	2.6.2 Existing Conditions
	Proposed	205 ft	4.2.4 Hydraulic Length
Structure type	Recommendation	No	4.2.6 Structure Type
	Type	N/A	4.2.6 Structure Type
Substrate	Existing	D_{50}= 0.5 in	2.7.3 Sediment
	Proposed	See Table 10	4.3.1 Bed Material
	Coarser than existing?	Yes	4.3.1 Bed Material
Channel complexity	LWM for bank stability	Yes	4.3.2.1 Design Concept

Stream crossing category	Element	Value	Report location
	LWM for habitat	Yes	4.3.2.1 Design Concept
	LWM within structure	No	4.3.2.1 Design Concept
	Meander bars	7	4.3.2.1 Design Concept
	Boulder clusters	N/A	4.3.2.1 Design Concept
	Half Channel Coarse bands	6	4.3.2.1 Design Concept
	Mobile wood	No	4.3.2.1 Design Concept
Floodplain continuity	FEMA mapped floodplain	No	6 Floodplain Evaluation
	Lateral migration	Yes	2.7.5 Channel Migration
	Floodplain changes?	Yes	6 Floodplain Evaluation
Scour	Analysis	See Table 19 (to be updated when scour sections are incorporated)	7 Scour Analysis
	Scour countermeasures	Determined at FHD	8 Scour Countermeasures
Channel degradation	Potential?	<1-foot	7.2 Long-term Aggradation/Degradation of the Channel Bed
Channel degradation	Allowed?	Yes	7.2 Long-term Aggradation/Degradation of the Channel Bed

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Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form

Appendix C: Streambed Material Sizing Calculations

Appendix D: Stream Plan Sheets, Profile, Details

Appendix E: Manning's Calculations

Appendix F: Large Woody Material Calculations

Appendix G: Future Projections for Climate-Adapted Culvert Design

Appendix H: SRH-2D Model Results

Appendix I: SRH-2D Model Stability and Continuity

Appendix J: Reach Assessment

Appendix K: Scour Calculations (FHD ONLY)

Appendix L: Floodplain Analysis (FHD ONLY)

Appendix M: Hydrology

Appendix A: FEMA Floodplain Map

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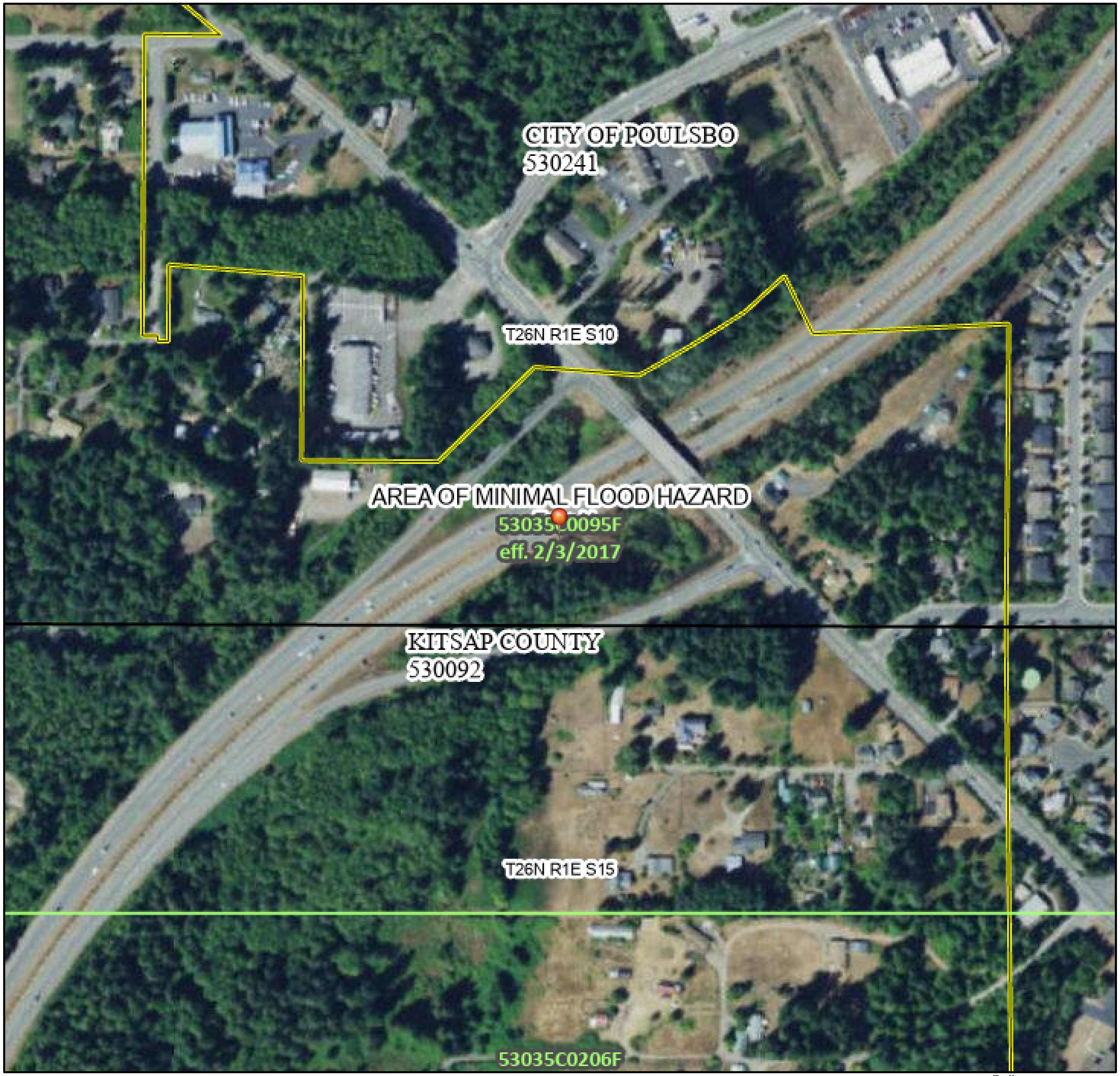
FEMA



/HJHQG

Appendix B: Hydraulic Field Report Form

Hydraulics Section	Hydraulics Field Report	Project Number:
	Project Name: PHD Johnson Creek to Liberty Bay	Date: Nov. 30, 2021
	Project Office: Jacobs Engineering Group Inc	Time of Arrival: 7:30 AM
	Stream Name: Johnson Creek	Time of Departure: 10:30 AM
WDFW ID Number: 991744	Tributary to: Liberty Bay	Weather: Cloudy, 50 degrees
State Route/MP: SR 3/52.21	Township/Range/Section/ ¼ Section:	Prepared By: K. Williams
County: Kitsap	Purpose of Site Visit: Site visit #2. Perform geomorphic assessment, pebble counts, measure BFW	WRIA: 15

Meeting Location:
On site

Attendance List:

Name	Organization	Role
Nicholas VanBuecken	Jacobs	Stream Engineer
Sage Jensen	Jacobs	Fisheries Biologist
Channing Syms	Jacobs	Stream Engineer
Mark Indrebo	Jacobs	Geomorphologist
Karen Williams	Jacobs	Geomorphologist
Morgan Ruark	Jacobs	Hydraulic Engineer

Bankfull Width:

Describe measurements, locations, known history, summarize on site discussion.

Bankfull width (BFW) measurements were made upstream and downstream of the SR 3 crossing. Upstream of the crossing, between the SR 3 crossing and the entrance ramp crossing, seven BFW measurements were made. Downstream of the SR 3 crossing, three BFW measurements were made. One of the upstream measurements was made on a tributary to Johnson Creek. BFW of the tributary was 3 ft. Upstream BFW measurements ranged from 4 – 7 ft. Downstream BFW measurements ranged from 7 to 9 ft. These measurements were collected over a total stream channel length of approximately 250 ft.

Reference Reach:

Describe location, known history, summarize on site discussion, appropriateness, bankfull measurement.

Reference reaches were identified approx. 50 ft upstream of the crossing and approx. 150 ft downstream of the crossing. Both reference reaches exhibit narrow and deep channel shape, run morphology, and stable banks. The upstream reference reach has full connection with the floodplain but little engagement with large woody material. The downstream reference reach has some interaction with LWM and less connection to the former floodplain. Banks in the downstream reference reach are generally steep to near vertical, with some undercutting at the toe. Bankfull width was measured at 7.0 and 8.8 feet in the downstream reference reach, but at the 7.0-foot location, the banks were undercut on both sides, indicating a propensity for widening. The suggested BFW for the upstream and downstream refence reaches is 5 and 9 feet, respectively.

Data Collection:

Describe who was involved, extents collection occurred within.

Data collection was performed by all team members listed above. Assessment occurred from the SR 3 entrance ramp crossing (~100 ft upstream of the crossing) to 150 ft downstream of the crossing, near the crossing of the exit ramp from SR 3.

Observations:

Describe site conditions, channel geomorphology, habitat type and location, flow splits, LWM location and quantity, etc.

This reach is located near the headwaters of Johnson Creek. The channel reaches upstream and downstream of the SR 3 crossing are distinct from each other. The upstream channel is characterized by active engagement with the floodplain, which is dominated by a closed canopy deciduous forest mid-seral stage deciduous forest dominated by red alder. Riparian width is greater than 150 ft on both sides of the stream. Wetlands were indicated throughout this reach by presence of facultative plants including red alder, salmonberry, sedge species and skunk cabbage. Dense deciduous floodplain trees provide leaf litter which create periodic accumulations that form steps in the channel. The upstream morphology is pool and run, and occasional riffle. Channel shape is narrow and relatively deep, simplified by lack of in-stream large wood. Channel banks have high silt and clay content and form cohesive steep banks (Photo 1). Bed substrate is characterized by finer (silt to sand) material. Suitable spawning gravels are limited and were observed primarily within the culvert and may have been artificially placed during installation of the culvert. There is limited woody debris either in or adjacent to the channel, comprised exclusively of smaller deciduous woody debris. The channel splits near the head of the upstream reach, facilitated by a downed alder. This split channel has a confluence with the tributary channel. The tributary channel has a confluence with the primary channel at an organic debris accumulation. The upstream reference reach, upstream and downstream of this confluence, exhibits stable channel banks, riffle/run morphology and floodplain engagement (Photo 2). Rearing and foraging habitat for salmonids is limited by the lack of channel complexity and lack of pool habitat. However, floodplain refugia and foraging may be present during high flow events where the stream can engage with its floodplain. A defined channel suggests year-round flow.

Downstream of the crossing, the channel is incised and disconnected from its former floodplain. However, the channel appears vertically stable and exhibits stable steep and undercut banks that provide the majority of cover and refugia for salmonids within this reach. Pervasive eroding banks were not observed. The former floodplain is dominated by mature conifer canopy with an open understory dominated by sword fern (Photo 3). At the culvert outlet, a stormwater pond adjacent to SR 3 drains into the channel. There is no evident erosion where the inflow enters the channel. A tributary from the right bank, which appears to originate from a smaller culvert under SR 3 west of the crossing, meets the channel approximately 80 feet downstream of the outlet. The tributary BFW was estimated to be approximately 2 feet wide, and flow at the time of the site visit was much less than the primary channel. LWM in the downstream reach consists of two approximately 10” DBH coniferous logs, one near the culvert outlet and one near the downstream end of the section surveyed, and in the middle, a constriction formed by a dead stump and a living cedar has captures small woody material creating a step (Photo 4).
Channel morphology is largely run and riffle with few pools facilitated by occasional wood pieces. Substrate consists of a higher percentage of gravels than was observed upstream of the culvert indicating suitable spawning habitat for anadromous and resident salmonids, though some substrate embeddedness was observed. Riparian cover is predominantly mature and mid-seral stage conifer trees dominated by Western red cedar, with a width of over 150 ft on either side of the stream. The riparian understory is dominated by sword fern and other closed canopy native shrubs and forbs.

Pebble Counts:

Describe location of pebble counts if available.

The upstream pebble count was collected approx. 75 ft upstream of the crossing and 10 ft upstream of the confluence with the tributary confluence.
Two downstream pebble counts were collected, one approximately 70 feet downstream of the outlet, just upstream of a small tributary from the right bank, and the other approximately 110 feet downstream of the crossing, upstream of the influence of the exit ramp culvert work.

Photos:

Any relevant photographs placed here with descriptions.

Photo 1. Upstream channel reach showing narrow width and adjacent floodplain.

Photo 2. Upstream reference reach, looking upstream.

Photo 3. Downstream reach - canopy dominated by mature conifers with fern undergrowth.

Photo 4 - Downstream reach - stump and live cedar trap smaller woody debris

Concurrence Meeting

Concurrence Meeting	Date: 2/15/2022	Time of Arrival: 10:00 AM
Prepared By: Jacobs Engineering Group Inc.	Weather: 40s and overcast	Time of Departure: 12:00 PM

Attendance List:

Name	Organization	Role
Mark Indrebo	Jacobs Engineering	Geomorphologist
Reilly Holland	Jacobs Engineering	Stream Restoration Engineer
Ben Dupuy	Jacobs Engineering	Stream Restoration Engineer
Kate Fauver	WSDOT	Senior Planner
Heather Pittman	WSDOT	OR Design Manager
Damon Romero	WSDOT	Fish Biologist
Dave Molenaar	WSDOT	Biology Program Manager
Hunter Henderson	WSDOT	Associate Planner
Alison O'Sullivan	Suquamish Tribe	Fish Biologist
Marla Powers	Port Gamble S'Klallam Tribe	Environmental Planner
Shawn Stanley	WDFW	Habitat Engineer
Amber Martens	WDFW	Biologist
Gina Piazza	WDFW	Biologist

Bankfull Width:

An upstream bankfull width (BFW) measurement was taken with all attendees and was determined to be 7.5 feet. The banks were low and consisted of soft, muddy material that suggested a potential channel width of 10 feet in areas. A downstream bankfull width (BFW) measurement was taken with all attendees and was determined to be 7.5 feet. All attendees agreed the design BFW should be 7.5 feet.

Reference Reach:

After evaluating both the upstream and downstream conditions, all attendees confirmed the reference reach will be upstream of the culvert, beginning approximately 50 feet from the inlet and extending approximately 100 feet, past the tributary that enters on the left bank. The upstream channel has better floodplain connectivity, and the surrounding area consists of extensive wetlands that should not be drained. The upstream reach has a similar gradient to the crossing, ranging from 3.1%-3.4%. The sediment should be sized based off the downstream conditions considering the upstream reach is mostly comprised of fine grain material.
Additional information on the reference reach can be found in the site visit two field report above.

Observations:

The site is highly constrained by culverts at the on- and off-ramps to Highway 3, as well as the tributaries that enter upstream and downstream of the crossing. High velocity at the outlet has resulted in an excessive amount of scour surrounding the outlet and coarse angular rock is exposed. The left bank, located directly in front of the outlet due to an immediate bend in the channel, is undercut approximately 15 inches as a result of this scour. The channel downstream of the crossing is downcut, and downcutting increases downstream of the off-ramp culvert. The mapped wetland upstream of the crossing could be disrupted if the downcutting is allowed to progress through the crossing and into the upstream reach.

The replacement crossing will be long and will require a culvert 30% wider than the MHO calculated with the Stream Simulation methodology. The proposed design should also accommodate the meander belt of the creek.

Upstream, at the confluence, there is also evidence of scour and backwater effects. The soil is completely saturated and the entire area between the on ramp and highway 3 has wetland characteristics and are mapped as wetlands. Wetland hydrology could be disrupted if the downcutting is allowed to progress through the crossing and into the upstream reach.

The gradient is steeper than desired for a riffle/pool morphology, so a step/pool with a tread concept, similar to Church and Zimmerman (2007) Figure 2C (below) was suggested in order to prevent the formation of a plane-bed system, which is a common channel type at this gradient. Participants had concerns about non-deformable steps, which could result in barriers, while WSDOT expressed concerns about using wood within the crossing to create deformable beds. The proposed design will seek to reduce the need for steps and the potential for steps to become barriers.

W03415 CHURCH AND ZIMMERMANN: RESEARCH PROGRESS ON STEP-POOL CHANNELS W03415

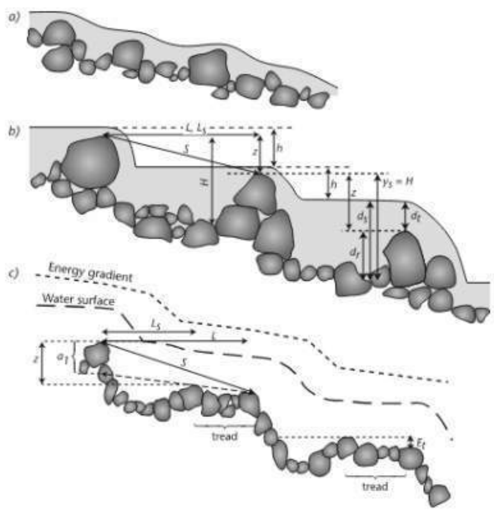


Figure 2. Illustrations with definitions of (a) rapid channel morphology, (b) a step-pool unit with no tread between successive pools (definitions given in the downstream pool are used particularly in studies of pool scour), and (c) a step-pool unit with a tread, extended forms of which may be considered equivalent to a run.

It was noted that the present crossing results in a near-90 degree bend at the outlet of the culvert. Shifting the downstream end of the proposed crossing to the right (southwest) could help make this bend less severe but would necessarily extend the culvert length. The design will attempt to strike a balance between these two outcomes.

This crossing is considered a medium complexity with the risk of degradation moved up to medium.

Photos:

Photo 1 – Upstream section reference reach

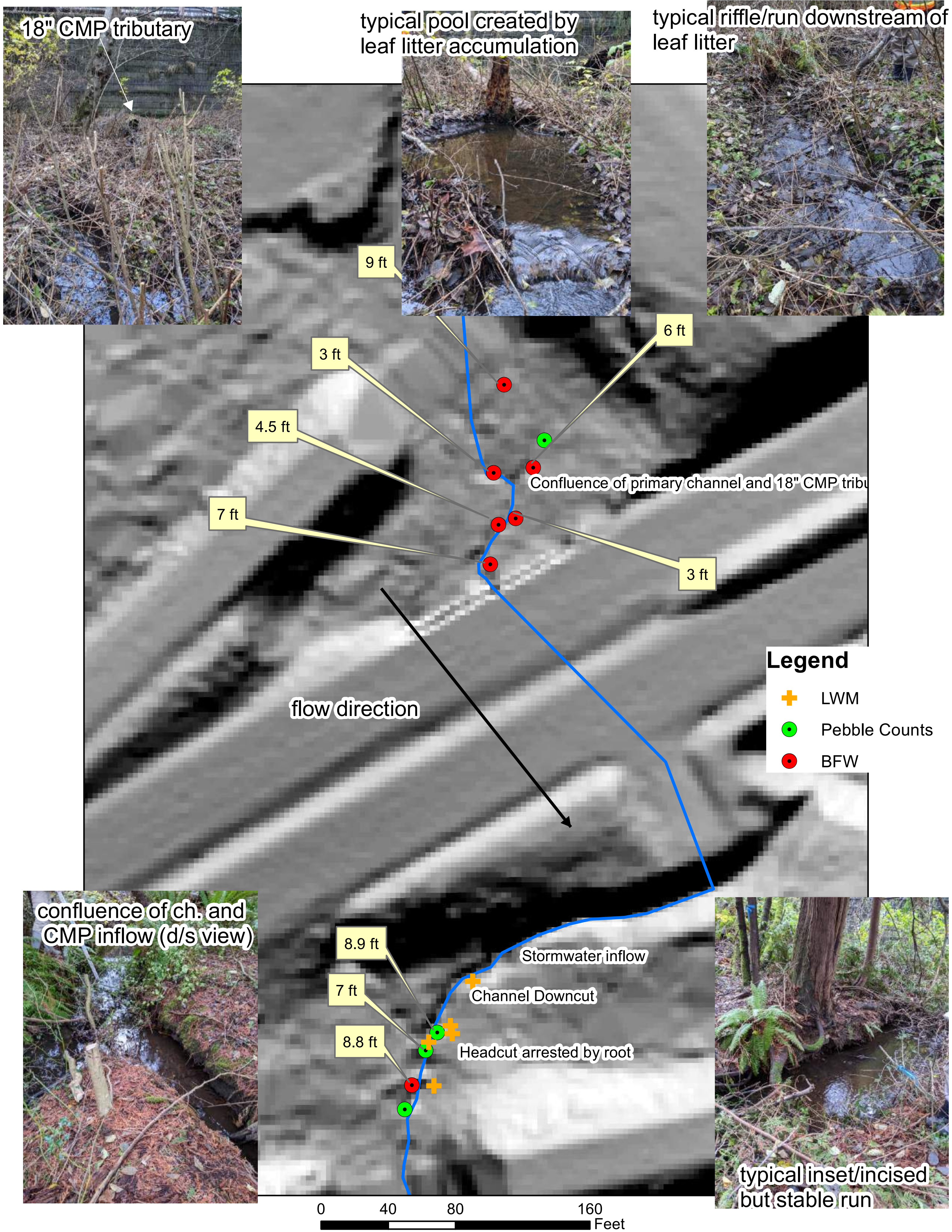
Photo 2 – Upstream confluence with the tributary

Photo 3 – 991744 culvert inlet


Photo 4 – 991744 culvert outlet and the angular rock at the outfall, approximately 18 inch drop


Photo 5 – Downstream scour directly in front of the culvert outlet

Photo 6 – Downstream Confluence



18" CMP tributary
typical pool created by leaf litter accumulation
typical riffle/run downstream of leaf litter
9 ft
6 ft
3 ft
4.5 ft
7 ft
3 ft
Confluence of primary channel and 18" CMP tribu
flow direction
Legend
LWM
Pebble Counts
BFW
confluence of ch. and CMP inflow (d/s view)
8.9 ft
7 ft
8.8 ft
Stormwater inflow
Channel Downcut
Headcut arrested by root
typical inset/incised but stable run
0
40
80
160
Feet

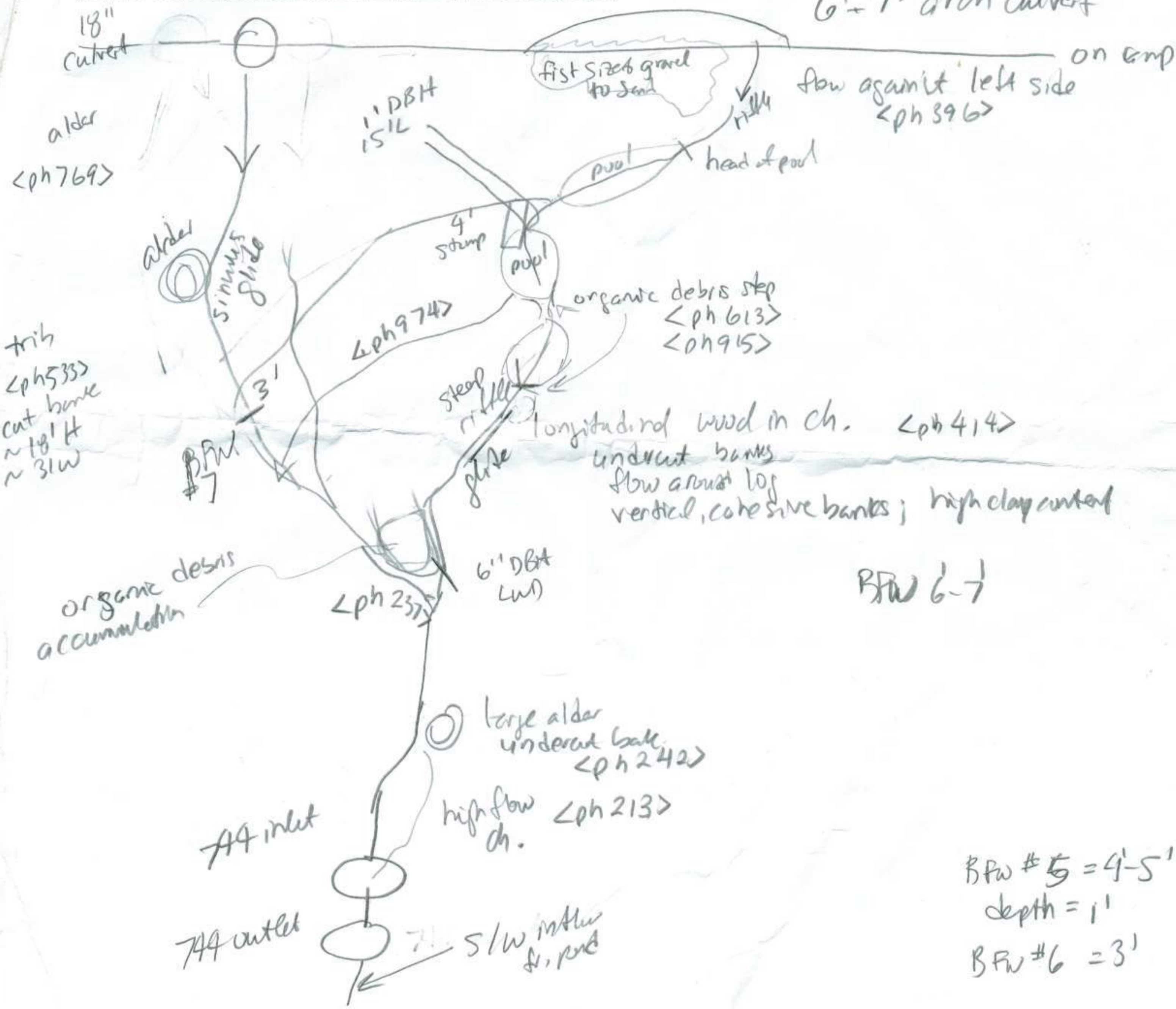
Johnson Cr to Liberty Bay u/S

Jacobs

CLIENT:	WSDOT		
JOB TITLE:	PHD ~~SF Johnson Crk to Johnson Crk SR 3 MP 50.85~~	BY: NV, PE	DATE: 11/30/2021
SUBJECT:	Stream Restoration: Site Sketch	CHECKED:	JOB #: ~~W3Y05003~~ 991744

GEOMORPHIC SITE SKETCH - INCLUDE STATIONING WITH ALL FEATURES AND ESTIMATED STABILITY RATING

Weather, stream flow depth, bankfull width measurement locations, thalweg alignment, cross section, profile, LWM, boulders, scour, aggradation/degradation, in channel and floodplain mannings, vegetation, site constraints, stream meander wavelengths and radius of curvature, north arrow, scale,



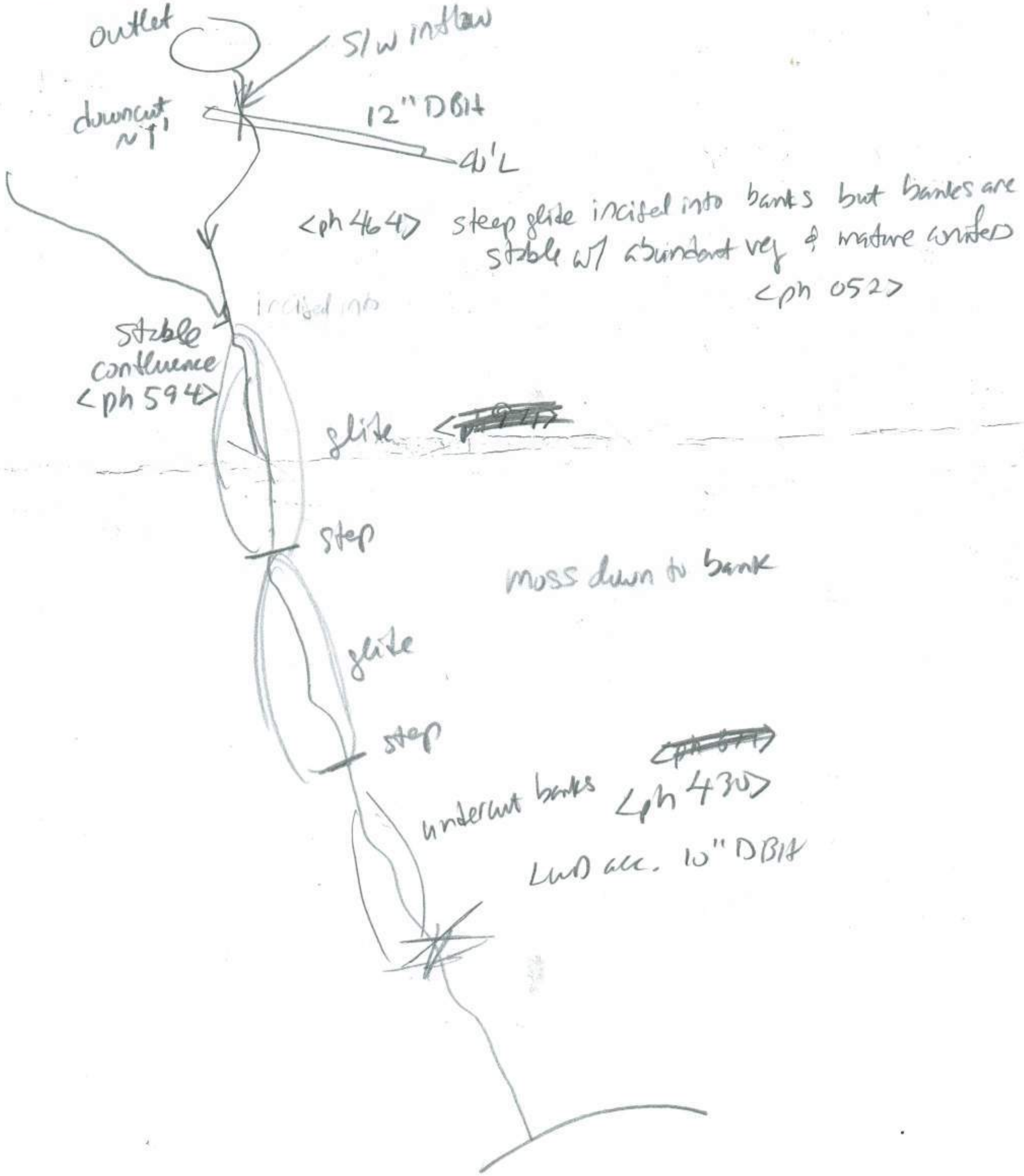
Johnson Cr. to Liberty Bay d/S

Jacobs

	CLIENT: WSDOT		
JOB TITLE:	PHD - ~~SF Johnson Crk to Johnson Crk SR 3 MP 50.65~~	BY: NV, PE	DATE: 11/30/2021
SUBJECT:	Stream Restoration: Site Sketch	CHECKED:	JOB #: ~~W3Y05003~~ 991744

GEOMORPHIC SITE SKETCH - INCLUDE STATIONING WITH ALL FEATURES AND ESTIMATED STABILITY RATING

Weather, stream flow depth, bankfull width measurement locations, thalweg alignment, cross section, profile, LWM, boulders, scour, aggradation/degradation, in channel and floodplain mannings, vegetation, site constraints, stream meander wavelengths and radius of curvature, north arrow, scale,



Fish Passage Project Site Visit - Determining Project Complexity

PROJECT NAME:	Johnson Creek
WDFW SITE ID:	991744
STATE ROUTE/MILEPOST:	SR 3 MP 52.21
SITE VISIT DATE:	12/1/2021
ATTENDEES:	Nich VanBuecken, Karen Williams, Sage Jensen, Channing Syms, Mark Indrebo
ANTICIPATED LEVEL OF PROJECT COMPLEXITY - Low/Medium/High (*additional considerations or red flags may trigger the need for new discussions*):	Medium due to long culvert, inflows and different channel types from upstream to downstream.
IN WATER WORK WINDOW	??

The following elements of projects should be discussed before the production of a Preliminary Hydraulic Design by members of WSDOT and WDFW to identify the level of complexity for each site, and corresponding communication and review. While certain elements may be categorized as indicators of a low/medium/high complexity project, these are only suggestions, and newly acquired information may change the level of complexity during a project. The ultimate documentation category for a given site is up to both WSDOT and WDFW, considering both site characteristics and synergistic effects.

Discuss the following elements as they apply to the project. Rank each element as low, medium, or high in complexity. If there are items that need follow-up, mark those and provide a brief description in the column labeled, "Is follow up needed on this item?" The assigned level of complexity determines the appropriate agreed upon review from WDFW (see review parameters here (*final full doc goes here*)). Ultimately, WSDOT needs to acquire an HPA from WDFW for fish passage projects and the agreed upon communication and review of project elements will contribute to efficiencies in the permitting process.

Fish Passage Project Site Visit - Determining Project Complexity

Project Elements (anticipated)	Low Complexity	Medium Complexity	High Complexity	Is follow up needed on this item?
Stream grading	X			limited channel regrade outside of crossing
Risk of degradation/aggradation	x			limited signs of high sediment load or active downcutting
Channel realignment	x			valley location set
Expected stream movement	x			mature trees and limited sediment load
Gradient		x		~3% culvert
Potential for backwater impacts		x		mapped wetlands at inlet
Meeting requirements for freeboard	x			high roadway prism
Stream size, and Bankfull Width	x			BFW 6-8 ft
Slope ratio	x			TBD
Sediment supply	x			no evident excess supply
Meeting stream simulation	x			
Channel confinement		x		from unconfined upstream to confined downstream
Geotech or seismic considerations	x			no evidence
Tidal influence	x			no
Alluvial fan	x			no
Fill depth above barrier			x	~15 ft upstream and downstream
Presence of other nearby barriers	x			unknown
Presence of nearby infrastructure	x			additional inflows (stormwater pond)
Need for bank protection	x			no acute ongoing erosion
Floodplain utilization ratio		x		appears unconfined upstream, confined downstream

Other:				

Appendix C: Streambed Material Sizing Calculations

Summary - Stream Simulation Bed Material Design

991744 SF Johnson Creek to Liberty Bay SBM- Main Channel

Project:	991744 SF Johnson Creek to Liberty Bay PHD
By:	J. Laundry, EIT
Checked By:	T. Bedford, PE

Design Gradation:

Location: Reference Reach Pebble Count Average

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.36	0.09	0.04	0.01
in	4.30	1.10	0.50	0.10
mm	109.22	27.94	12.70	2.54

Design Gradation:

Location: Design Gradadtion

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.33	0.18	0.05	0.00
in	4.00	2.19	0.60	0.02
mm	101.60	55.59	15.19	0.48

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organizms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

Sand/gravel streams with high relative submergence

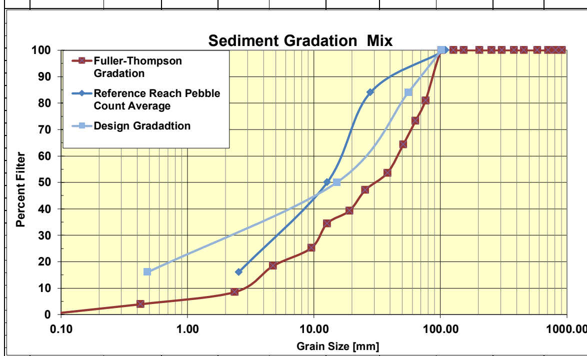
γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.048	dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

	Rock Size [in]	Rock Size [mm]	Streambed Sand	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}	τ_{ci}	Flow 2-YR (27 cfs)	Flow 100-YR (88 cfs)
														Average Modeled Shear Stress (lb	0.60	1.10
Boulders	36.0	914										100	100.0	0.84	No Motion	Motion
	32.0	813										50	100.0	0.81	No Motion	Motion
	28.0	711									100		100.0	0.78	No Motion	Motion
	23.0	584									50		100.0	0.73	No Motion	Motion
	18.0	457								100			100.0	0.68	No Motion	Motion
	15.0	381								50			100.0	0.65	No Motion	Motion
Cobbles	12.0	305							100				100.0	0.60	No Motion	Motion
	10.0	254						100	80				100.0	0.57	Motion	Motion
	8.0	203					100	80	68				100.0	0.53	Motion	Motion
	6.0	152				100	80	68	57				100.0	0.49	Motion	Motion
	5.0	127				80	68	57	45				100.0	0.46	Motion	Motion
	4.0	102			100	71	57	45	39				100.0	0.43	Motion	Motion
Gravel	3.0	76.2			80	63	45	38	34				97.0	0.40	Motion	Motion
	2.5	63.5		100	65	54	37	32	28				94.8	0.38	Motion	Motion
	2.0	50.8		80	50	45	29	25	22				77.5	0.35	Motion	Motion
	1.5	38.1		73	35	32	21	18	16				69.6	0.32	Motion	Motion
	1.0	25.4		65	20	18	13	12	11				61.8	0.29	Motion	Motion
	0.75	19.1		58	5	5	5	5	5				53.9	0.26	Motion	Motion
	0.50	12.7	100	50									47.5	0.23	Motion	Motion
	0.38	9.5	90	43									40.9	0.21	Motion	Motion
	No. 4 =	4.75	79	35									34.1			
	No. 8 =	2.36	67	26									25.8	Max Tau =	0.36	
Sand	No. 40 =	0.425	37	16									15.7	Flow	2-YR (27 cfs)	100-YR (88 cfs)
Silt	No. 200 =	0.0750	7	7									6.0	D84 FOS	0.6	0.3
	% per category		10	75	15	0	0	0	0	0	0	0	--> 100%			
	% Cobble & Sediment		10.0	50.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0%			

%	mm	in	ft
15.7	0.4	0.0	0.001
16	0.5	0.02	0.002
25.8	2.4	0.1	0.008
47.50	12.7	0.5	0.042
50	15.2	0.60	0.050
53.88	19.1	0.8	0.063
77.50	50.8	2.0	0.167
84	55.6	2.19	0.182
94.75	63.5	2.5	0.208



Fuller-Thompson Gradation

Dmax = 101.6 | 4

D[mm]	D[in]	% passing
914.400	36	100.00
812.800	32	100.00
711.200	28	100.00
584.200	23	100.00
457.200	18	100.00
381.000	15	100.00
304.800	12	100.00
254.000	10	100.00
203.200	8	100.00
152.400	6	100.00
127.000	5	100.00
101.600	4	100.00
76.200	3	80.94
63.500	2.5	73.20
50.800	2	64.32
38.100	1.5	53.59
25.400	1.00	47.08
19.050	0.75	39.23
12.700	0.50	34.47
9.525	0.375	25.20
4.750	0.187	18.40
2.360	0.093	8.50
0.425	0.017	3.90
0.075	0.0030	0.00

Summary - Stream Simulation Bed Material Design

991744 SF Johnson Creek to Liberty Bay SBM- Meander Bar Structure Head

Project:	991744 SF Johnson Creek to Liberty Bay PHD
By:	J. Laundry, EIT
Checked By:	T. Bedford, PE

Design Gradation:				
Location:	Reference Reach Pebble Count Average			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.36	0.09	0.04	0.01
in	4.30	1.10	0.50	0.10
mm	109.22	27.94	12.70	2.54

Design Gradation:				
Location:	Design Gradadtion			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	1.50	1.18	0.35	0.06
in	18.00	14.16	4.23	0.70
mm	457.20	359.66	107.52	17.78

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organizms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

Sand/gravel streams with high relative submergence

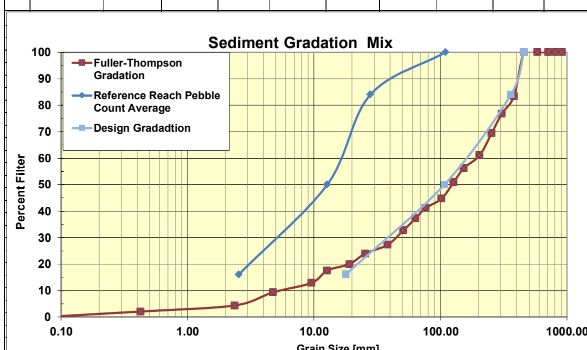
γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.052	dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

	Rock Size [in]	Rock Size [mm]	Streambed Sand	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}	τ_{ci}	2-YR (27 cfs)	100-YR (88 cfs)
														Average Modeled Shear Stress (lb	0.15	1.08
Boulders	36.0	914										100	100.0	3.58	No Motion	No Motion
Boulders	32.0	813										50	100.0	3.45	No Motion	No Motion
Boulders	28.0	711									100		100.0	3.32	No Motion	No Motion
Boulders	23.0	584									50		100.0	3.13	No Motion	No Motion
Boulders	18.0	457								100			100.0	2.91	No Motion	No Motion
Boulders	15.0	381								50			87.5	2.75	No Motion	No Motion
Cobbles	12.0	305							100				75.0	2.57	No Motion	No Motion
Cobbles	10.0	254						100	80				70.0	2.44	No Motion	No Motion
Cobbles	8.0	203					100	80	68				67.1	2.28	No Motion	No Motion
Cobbles	6.0	152				100	80	68	57				59.2	2.09	No Motion	No Motion
Cobbles	5.0	127				80	68	57	45				53.3	1.98	No Motion	No Motion
Cobbles	4.0	102			100	71	57	45	39				49.0	1.85	No Motion	No Motion
Gravel	3.0	76.2			80	63	45	38	34				44.6	1.70	No Motion	No Motion
Gravel	2.5	63.5		100	65	54	37	32	28				41.2	1.61	No Motion	No Motion
Gravel	2.0	50.8		80	50	45	29	25	22				32.8	1.50	No Motion	No Motion
Gravel	1.5	38.1		73	35	32	21	18	16				27.5	1.38	No Motion	No Motion
Gravel	1.0	25.4		65	20	18	13	12	11				22.2	1.22	No Motion	No Motion
Gravel	0.75	19.1		58	5	5	5	5	5				16.9	1.12	No Motion	No Motion
Gravel	0.50	12.7	100	50									12.5	0.99	No Motion	Motion
Gravel	0.38	9.5	90	43									10.6	0.91	No Motion	Motion
Gravel	No. 4 =	4.75	79	35									8.8			
Gravel	No. 8 =	2.36	67	26									6.4	Max Tau =	2.70	
Sand	No. 40 =	0.425	37	16									4.0	Flow	2-YR (27 cfs)	100-YR (88 cfs)
Silt	No. 200 =	0.0750	7	7									1.8	D84 FOS	18.0	2.5
% per category			0	25	0	0	25	0	25	25	0	0	--> 100%			
% Cobble & Sediment			0.0	25.0	0.0	0.0	25.0	0.0	25.0	25.0	0.0	0.0	100.0%			

%	mm	in	ft
12.5	12.7	0.5	0.042
16	17.8	0.7	0.058
16.9	19.1	0.8	0.063
48.99	101.6	4.0	0.333
50	107.5	4.2	0.353
53.33	127.0	5.0	0.417
75.00	304.8	12.0	1.000
84	359.7	14.2	1.180
87.50	381.0	15.0	1.250



Fuller-Thompson Gradation

Dmax =	457.2	18
D[mm]	D[in]	% passing
914.400	36	100.00
812.800	32	100.00
711.200	28	100.00
584.200	23	100.00
457.200	18	100.00
381.000	15	83.32
304.800	12	76.76
254.000	10	69.43
203.200	8	61.00
152.400	6	56.19
127.000	5	50.82
101.600	4	44.65
76.200	3	41.13
63.500	2.5	37.20
50.800	2	32.69
38.100	1.5	27.23
25.400	1.00	23.93
19.050	0.75	19.94
12.700	0.50	17.52
9.525	0.375	12.81
4.750	0.187	9.35
2.360	0.093	4.32
0.425	0.017	1.98
0.075	0.0030	0.00

Summary - Stream Simulation Bed Material Design

991744 SF Johnson Creek to Liberty Bay SBM- Meander Bar Structure Tail

Project:	991744 SF Johnson Creek to Liberty Bay PHD
By:	J. Laundry, EIT
Checked By:	T. Bedford, PE

Design Gradation:

Location: Reference Reach Pebble Count Average

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.36	0.09	0.04	0.01
in	4.30	1.10	0.50	0.10
mm	109.22	27.94	12.70	2.54

Design Gradation:

Location: Design Gradadtion

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.67	0.48	0.19	0.05
in	8.00	5.76	2.25	0.54
mm	203.20	146.18	57.04	13.80

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organizms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.05	dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

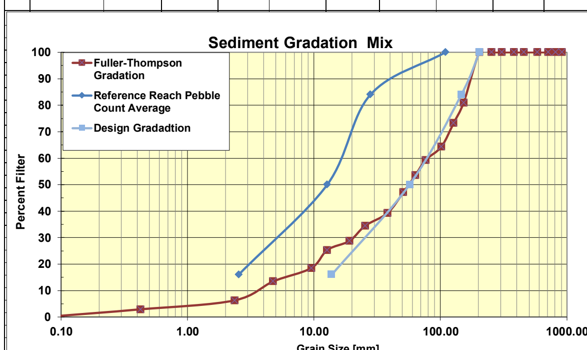
Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

	Flow	2-YR (27 cfs)	100-YR (88 cfs)
	Average Modeled Shear Stress (lb	0.15	1.08

	Rock Size [in]	[mm]	Streambed Sand	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}	τ_{ci}	2-YR (27 cfs)	100-YR (88 cfs)
Boulders	36.0	914										100	100.0	2.21	No Motion	No Motion
	32.0	813										50	100.0	2.13	No Motion	No Motion
	28.0	711									100		100.0	2.05	No Motion	No Motion
	23.0	584									50		100.0	1.93	No Motion	No Motion
	18.0	457								100			100.0	1.79	No Motion	No Motion
	15.0	381								50			100.0	1.70	No Motion	No Motion
Cobbles	12.0	305							100				100.0	1.59	No Motion	No Motion
	10.0	254						100	80				100.0	1.50	No Motion	No Motion
	8.0	203					100	80	68				100.0	1.41	No Motion	No Motion
	6.0	152				100	80	68	57				86.0	1.29	No Motion	No Motion
	5.0	127				80	68	57	45				77.8	1.22	No Motion	No Motion
	4.0	102			100	71	57	45	39				69.7	1.14	No Motion	No Motion
Gravel	3.0	76.2			80	63	45	38	34				61.5	1.05	No Motion	Motion
	2.5	63.5		100	65	54	37	32	28				55.9	0.99	No Motion	Motion
	2.0	50.8		80	50	45	29	25	22				44.3	0.93	No Motion	Motion
	1.5	38.1		73	35	32	21	18	16				36.5	0.85	No Motion	Motion
	1.0	25.4		65	20	18	13	12	11				28.6	0.75	No Motion	Motion
	0.75	19.1		58	5	5	5	5	5				20.8	0.69	No Motion	Motion
	0.50	12.7	100	50									15.0	0.61	No Motion	Motion
	0.38	9.5	90	43									12.8	0.56	No Motion	Motion
	No. 4 =	4.75	79	35									10.5			
	No. 8 =	2.36	67	26									7.7	Max Tau =	1.27	
Sand	No. 40 =	0.425	37	16									4.8	Flow	2-YR (27 cfs)	100-YR (88 cfs)
Silt	No. 200 =	0.0750	7	7									2.1	D84 FOS	8.5	1.2
	% per category		0	30	0	0	70	0	0	0	0	0	--> 100%			
	% Cobble & Sediment		0.0	30.0	0.0	0.0	70.0	0.0	0.0	0.0	0.0	0.0	100.0%			

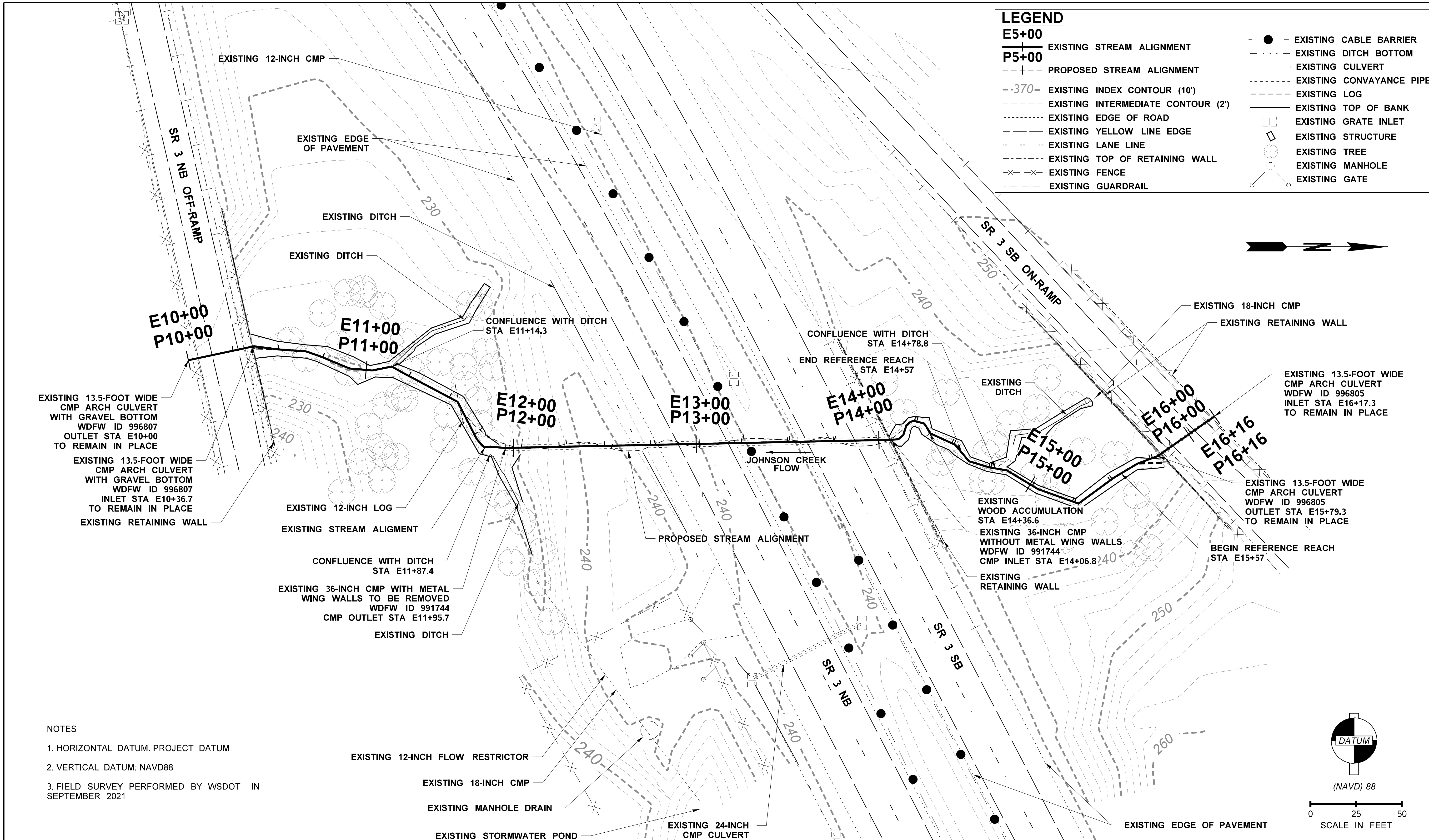
%	mm	in	ft
15.0	12.7	0.5	0.042
16	13.8	0.5	0.045
20.8	19.1	0.8	0.063
44.30	50.8	2.0	0.167
50	57.0	2.2	0.187
55.90	63.5	2.5	0.208
77.83	127.0	5.0	0.417
84	146.2	5.8	0.480
86.00	152.4	6.0	0.500



Fuller-Thompson Gradation

Dmax =	203.2	8
D[mm]	D[in]	% passing
914.400	36	100.00
812.800	32	100.00
711.200	28	100.00
584.200	23	100.00
457.200	18	100.00
381.000	15	100.00
304.800	12	100.00
254.000	10	100.00
203.200	8	100.00
152.400	6	80.94
127.000	5	73.20
101.600	4	64.32
76.200	3	59.25
63.500	2.5	53.59
50.800	2	47.08
38.100	1.5	39.23
25.400	1.00	34.47
19.050	0.75	28.72
12.700	0.50	25.23
9.525	0.375	18.45
4.750	0.187	13.47
2.360	0.093	6.23
0.425	0.017	2.85
0.075	0.0030	0.00

Appendix D: Stream Plan Sheets, Profile, Details



NOTES

1. HORIZONTAL DATUM: PROJECT DATUM
2. VERTICAL DATUM: NAVD88
3. FIELD SURVEY PERFORMED BY WSDOT IN SEPTEMBER 2021

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DATE	11/8/2022			
PLOTTED BY	HollanRA			
DESIGNED BY	R. HOLLAND			
ENTERED BY	R. HOLLAND			
CHECKED BY	K. WILLIAMS			
PROJ. ENGR.	J. HEILMAN			
REGIONAL ADM.	-	REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.
JOB NUMBER Y-12554
CONTRACT NO. C1744 | LOCATION NO.

PRELIMINARY
NOT FOR CONSTRUCTION
DATE P.E. STAMP BOX
DATE P.E. STAMP BOX

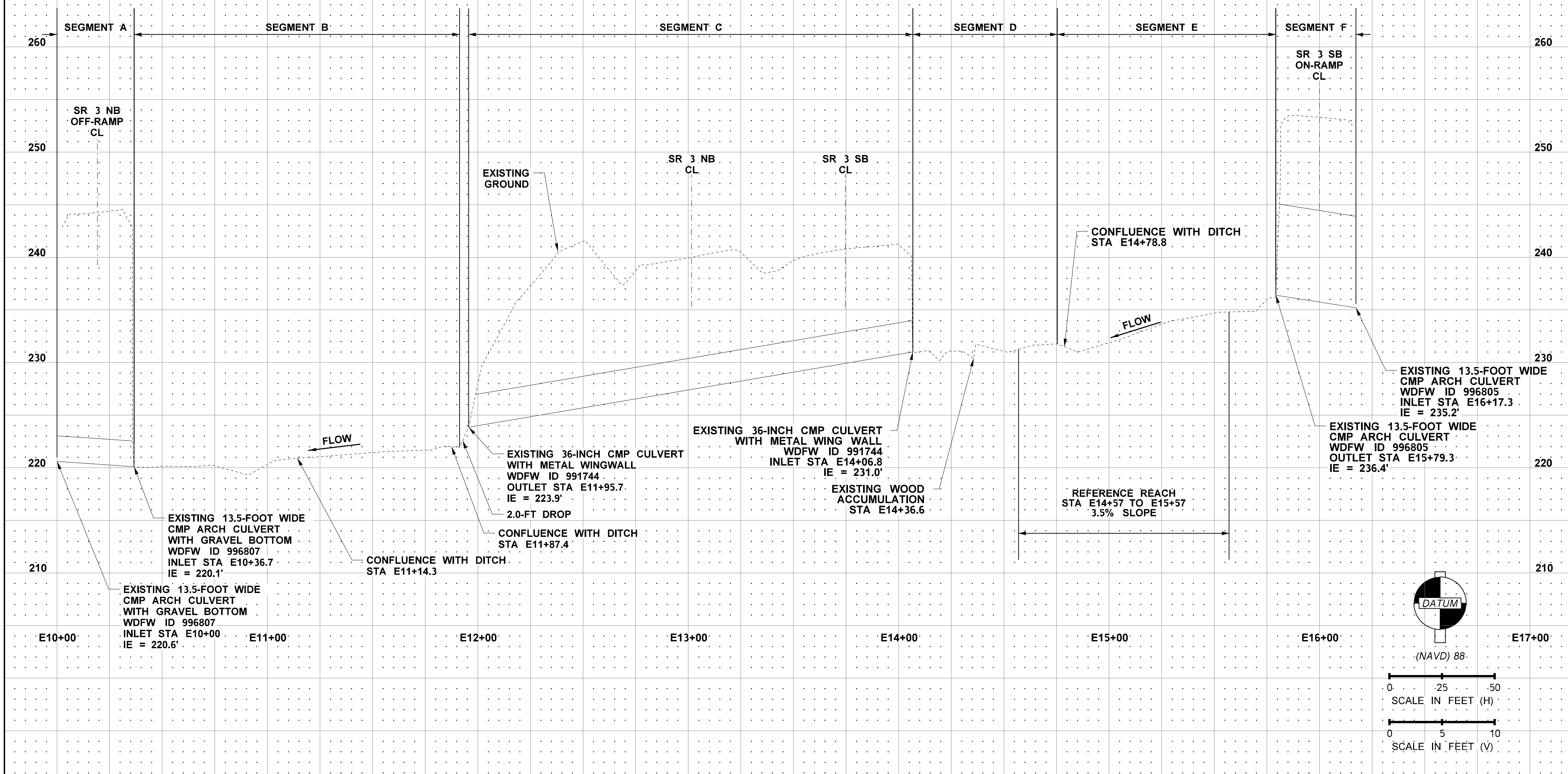
Washington State Department of Transportation

SR 3 MILE POST 52.21
991744 JOHNSON CREEK TO LIBERTY BAY FISH BARRIER REMOVAL

EXISTING STREAM PLAN

PLAN REF NO CE1
SHEET 1 OF 5 SHEETS

991744 JOHNSON CREEK TO LIBERTY BAY				
SEGMENT	ELEVATION CHANGE (FT)	SEGMENT LENGTH (FT)	GRADIENT	MAX POOL DEPTH (FT)
A (996807)	-0.6	36.7	-1.5%	0.0
B	1.9	154.6	1.2%	1.4
C (991744)	7.1	211.1	3.4%	0.0
D	0.8	68.6	1.2%	1.3
E	4.6	103.9	4.4%	0.8
F (996805)	-1.2	38.0	-3.3%	0.0



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DESIGNED BY	R. HOLLAND
ENTERED BY	R. HOLLAND
CHECKED BY	K. WILLIAMS
PROJ. ENGR.	J. HEILMAN
REGIONAL ADM.	-

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	

JOB NUMBER Y-12554

CONTRACT NO. C1744

LOCATION NO.

PRELIMINARY

NOT FOR CONSTRUCTION

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

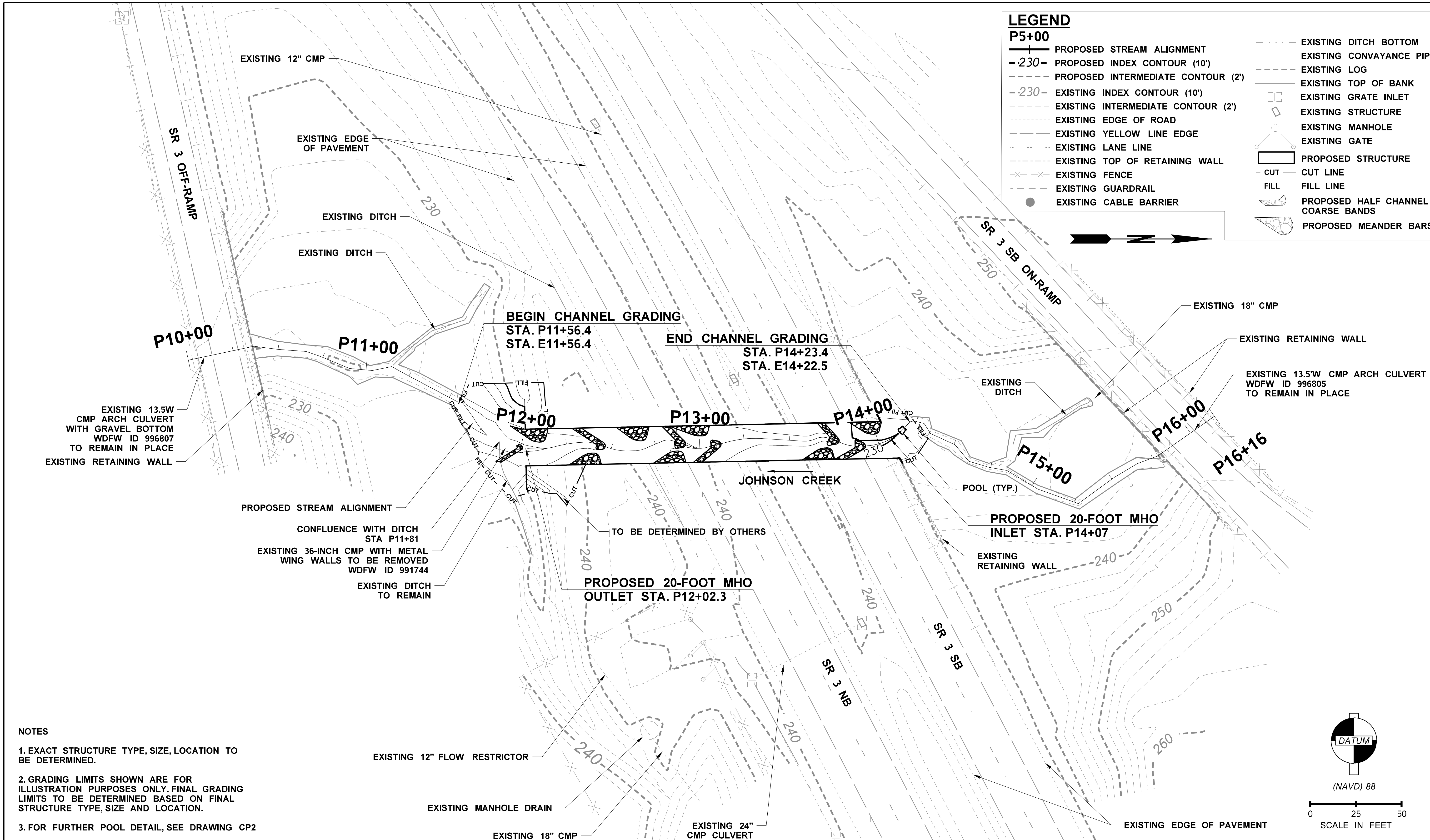
Washington State Department of Transportation

SR 3 MILE POST 52.21
991744 JOHNSON CREEK TO LIBERTY BAY
FISH BARRIER REMOVAL

EXISTING STREAM PROFILE

PLAN REF NO CP1

SHEET 2 OF 7 SHEETS



NOTES

1. EXACT STRUCTURE TYPE, SIZE, LOCATION TO BE DETERMINED.

2. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL GRADING LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE TYPE, SIZE AND LOCATION.

3. FOR FURTHER POOL DETAIL, SEE DRAWING CP2

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DATE	11/8/2022
PLOTTED BY	HollanRA
DESIGNED BY	R. HOLLAND
ENTERED BY	R. HOLLAND
CHECKED BY	K. WILLIAMS
PROJ. ENGR.	J. HEILMAN
REGIONAL ADM.	-

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER Y-12554

CONTRACT NO. C1744 | LOCATION NO.

PRELIMINARY

NOT FOR CONSTRUCTION

P.E. STAMP BOX DATE | P.E. STAMP BOX DATE

Washington State Department of Transportation

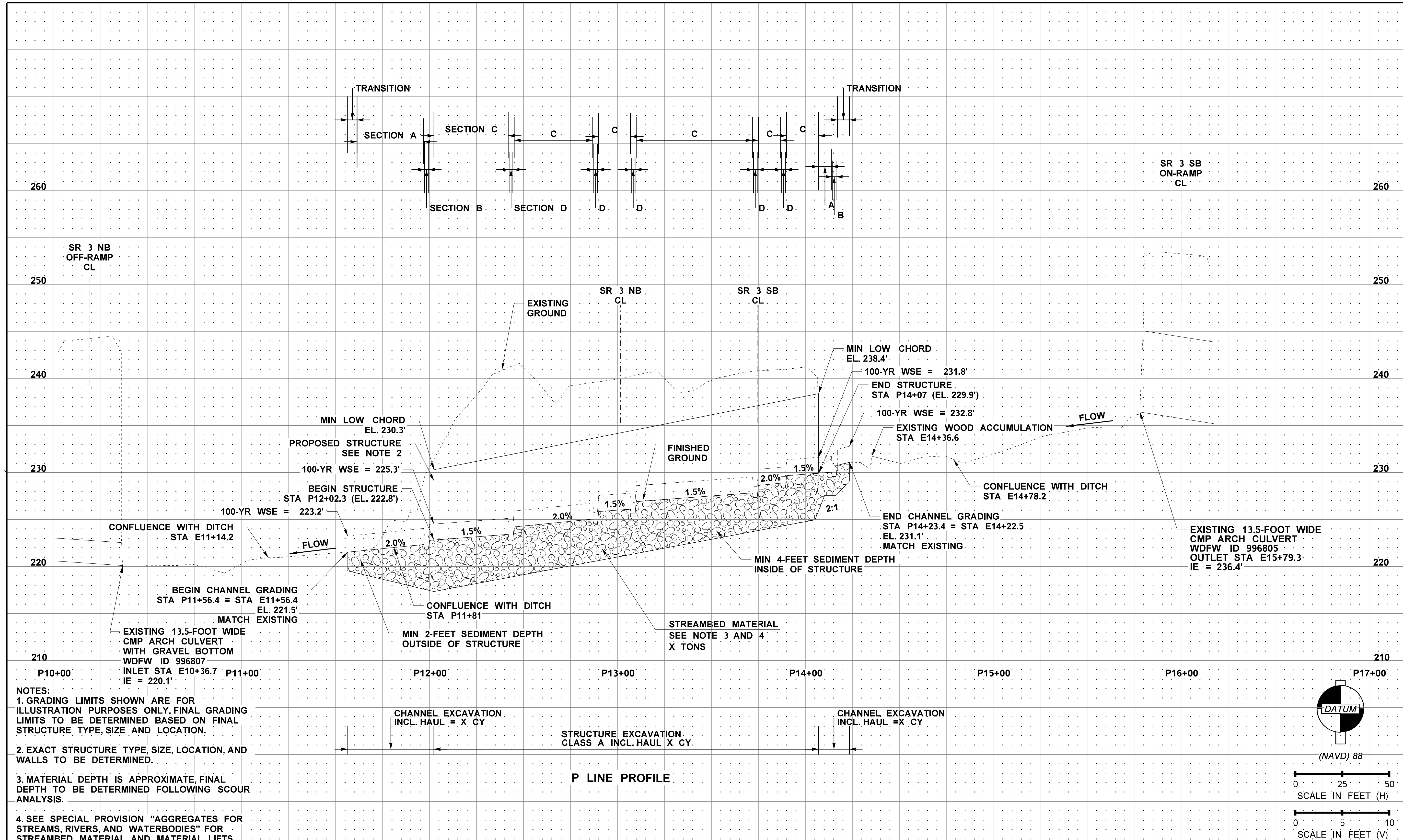
SR 3 MILE POST 52.21

991744 JOHNSON CREEK TO LIBERTY BAY FISH BARRIER REMOVAL

PROPOSED STREAM PLAN

PLAN REF NO CR1

SHEET 3 OF 7 SHEETS



NOTES:
1. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL GRADING LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE TYPE, SIZE AND LOCATION.

2. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED.

3. MATERIAL DEPTH IS APPROXIMATE, FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.

4. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND MATERIAL LIFTS.

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DATE	11/8/2022
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DESIGNED BY	R. HOLLAND
ENTERED BY	R. HOLLAND
CHECKED BY	K. WILLIAMS
PROJ. ENGR.	J. HEILMAN
REGIONAL ADM.	-

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.
JOB NUMBER Y-12554
CONTRACT NO. C1744 | LOCATION NO.

PRELIMINARY
NOT FOR CONSTRUCTION

P.E. STAMP BOX DATE | P.E. STAMP BOX DATE

Washington State Department of Transportation

SR 3 MILE POST 52.21
991744 JOHNSON CREEK TO LIBERTY BAY FISH BARRIER REMOVAL

PROPOSED STREAM PROFILE

PLAN REF NO CP2
SHEET 4 OF 7 SHEETS

NOTES:

1. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION.

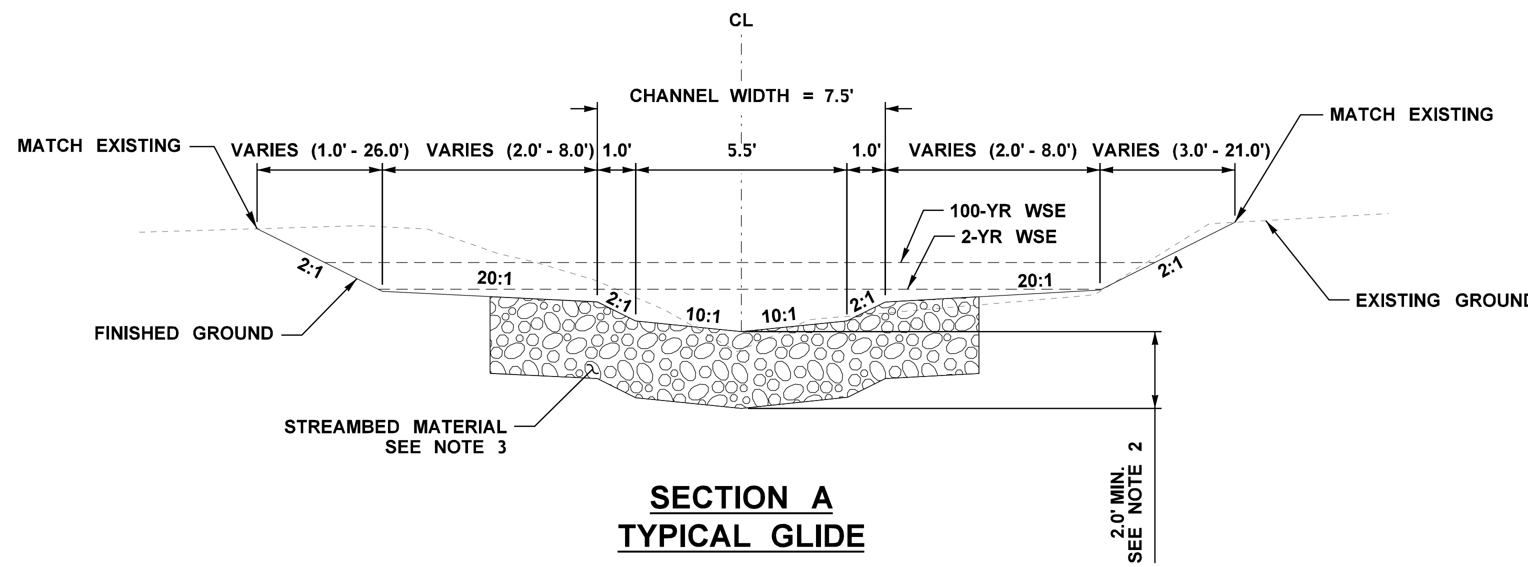
2. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.

3. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND MATERIAL LIFTS.

4. FROM P11+56.4 TO P11+61.4, EVENLY TAPER SECTION A TO MATCH EXISTING CHANNEL.

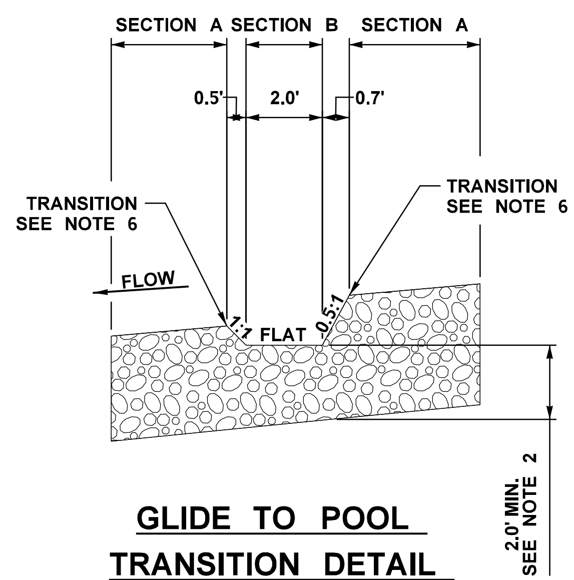
5. FROM P14+18.4 TO P14+23.4, EVENLY TAPER SECTION A TO MATCH EXISTING CHANNEL.

6. EVENLY TAPER SECTION A TO SECTION B USING A 0.5:1 SLOPE. EVENLY TAPER SECTION B TO SECTION A USING A 1:1 SLOPE.

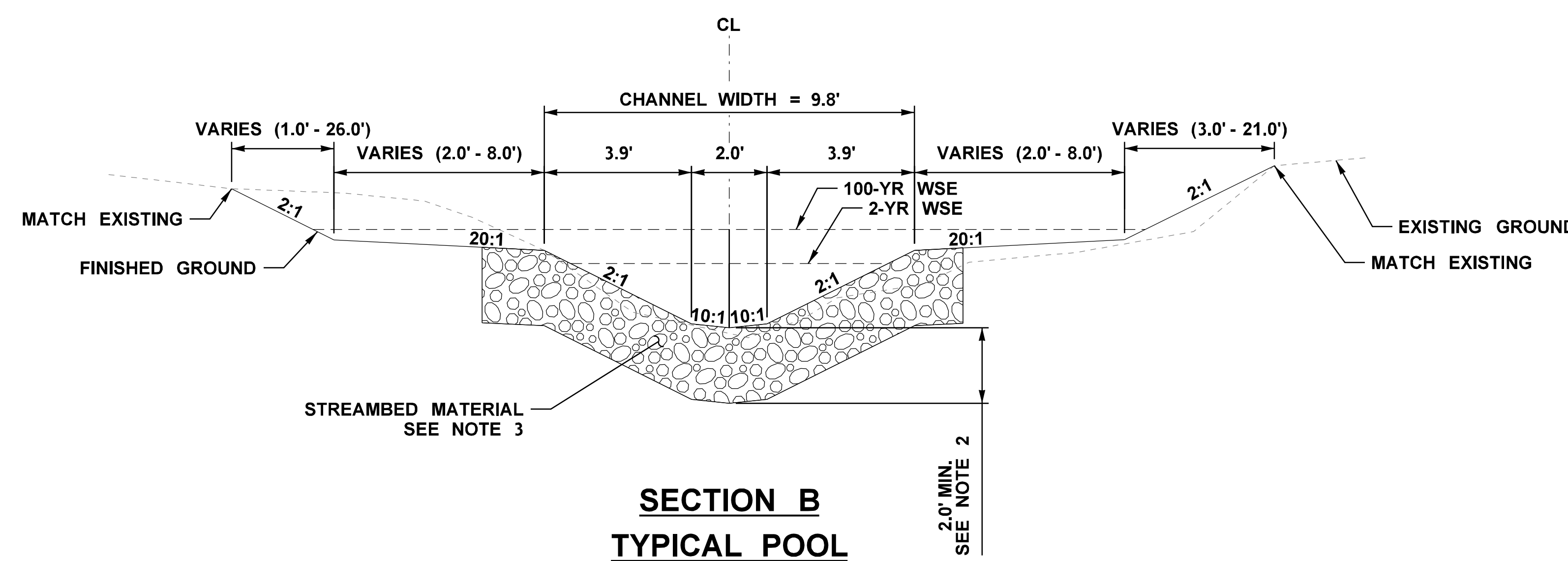


SECTION A
TYPICAL GLIDE

STA P11+61.4 TO STA P11+96.9
STA P12+00.0 TO STA P12+02.3
STA P14+07.0 TO STA P14+13.9
STA P14+17.0 TO STA P14+18.4



GLIDE TO POOL
TRANSITION DETAIL
BETWEEN SECTION A AND SECTION B



SECTION B
TYPICAL POOL

STA P11+97.4 TO STA P11+99.4
STA P14+14.4 TO STA P14+16.4

DATUM

(NAVD) 88

0 2.5 5
SCALE IN FEET (H)

0 2.5 5
SCALE IN FEET (V)

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DESIGNED BY	R. HOLLAND			
ENTERED BY	R. HOLLAND			
CHECKED BY	K. WILLIAMS			
PROJ. ENGR.	J. HEILMAN			
REGIONAL ADM.	-	REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
Y-12554		
CONTRACT NO.		LOCATION NO.
C1744		

PRELIMINARY
NOT FOR CONSTRUCTION

P.E. STAMP BOX DATE
P.E. STAMP BOX DATE

Washington State Department of Transportation

SR 3 MILE POST 52.21
991744 JOHNSON CREEK TO LIBERTY BAY
FISH BARRIER REMOVAL

PROPOSED CROSS SECTION SHEET 1 OF 2

PLAN REF NO CD1

SHEET 5 OF 7 SHEETS

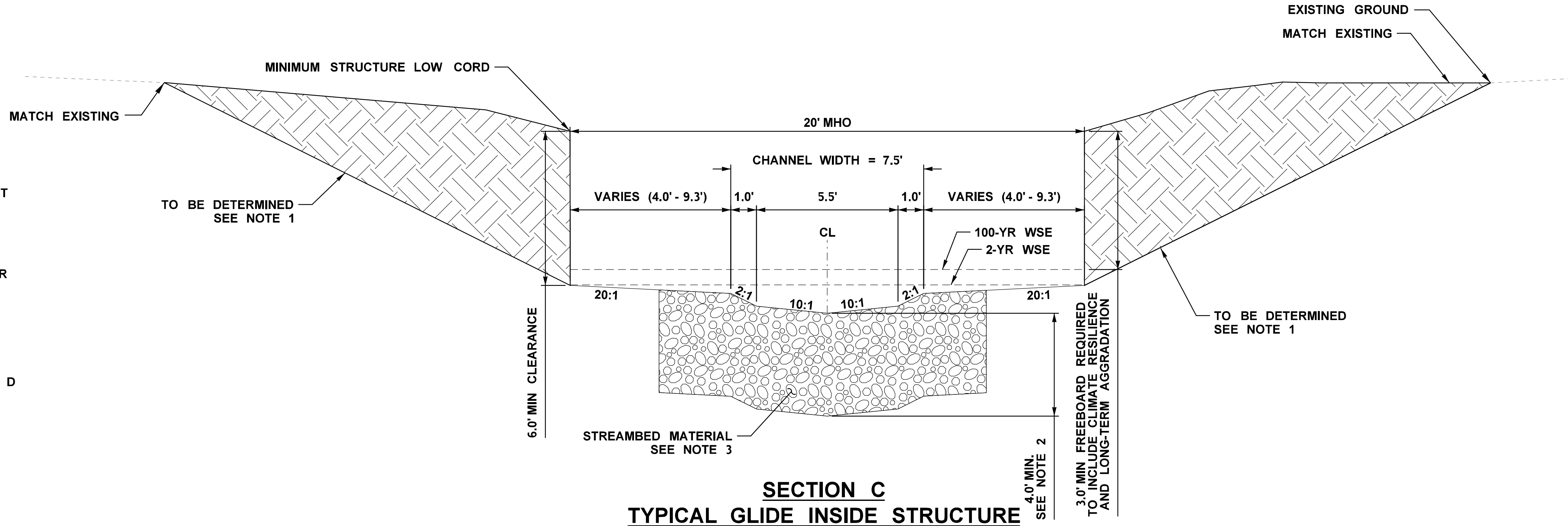
NOTES:

1. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION.

2. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.

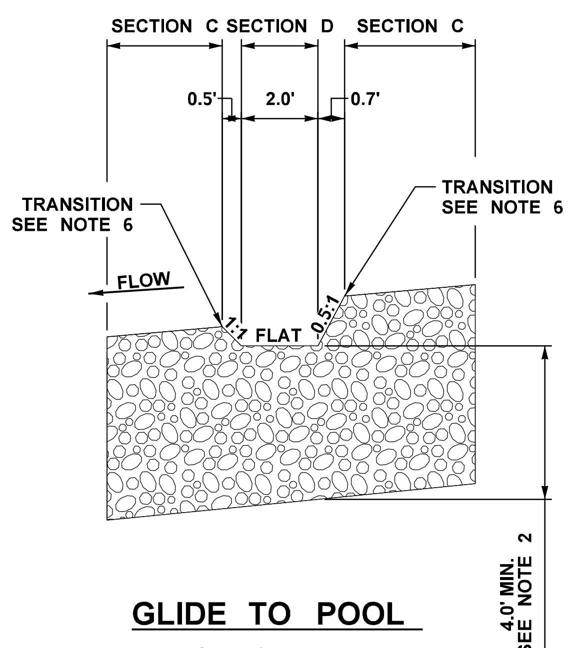
3. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND MATERIAL LIFTS.

4. EVENLY TAPER SECTION C TO SECTION D USING A 0.5:1 SLOPE. EVENLY TAPER SECTION D TO SECTION C USING A 1:1 SLOPE.

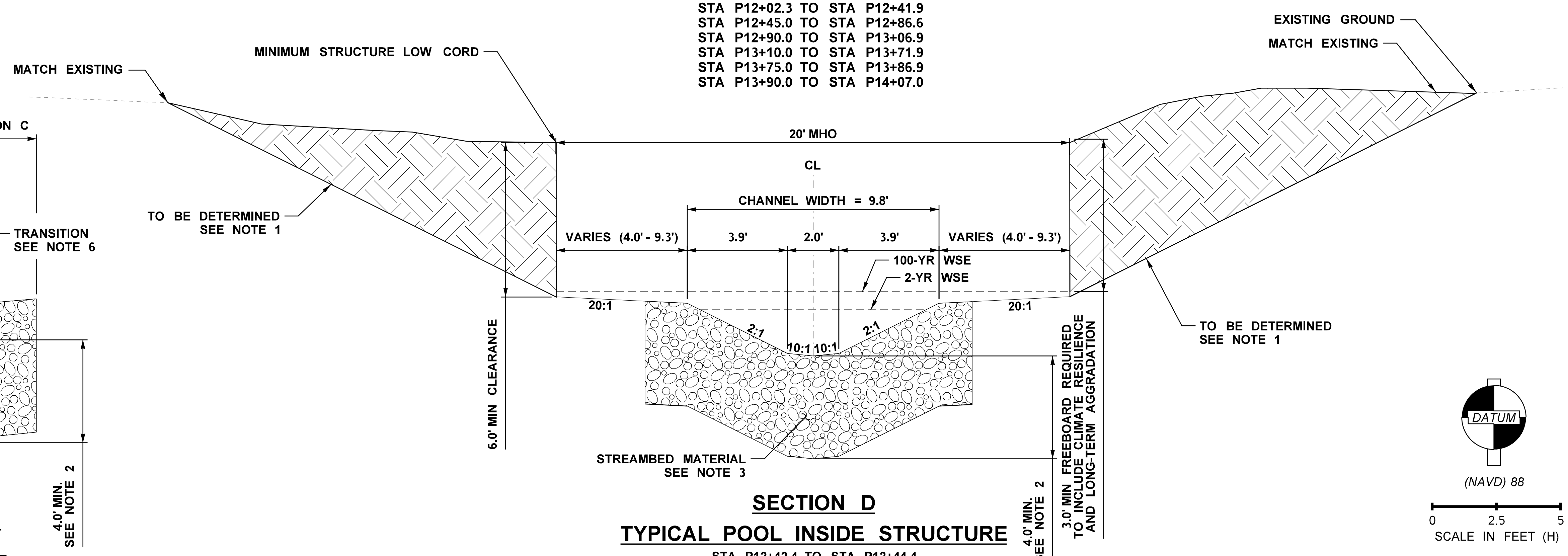


SECTION C
TYPICAL GLIDE INSIDE STRUCTURE

STA P12+02.3 TO STA P12+41.9
STA P12+45.0 TO STA P12+86.6
STA P12+90.0 TO STA P13+06.9
STA P13+10.0 TO STA P13+71.9
STA P13+75.0 TO STA P13+86.9
STA P13+90.0 TO STA P14+07.0



GLIDE TO POOL
TRANSITION DETAIL
BETWEEN SECTION C AND SECTION D



SECTION D
TYPICAL POOL INSIDE STRUCTURE

STA P12+42.4 TO STA P12+44.4
STA P12+87.4 TO STA P12+89.4
STA P13+07.4 TO STA P13+09.4
STA P13+72.4 TO STA P13+74.4
STA P13+87.4 TO STA P13+89.4

DATUM
(NAVD) 88

0 2.5 5
SCALE IN FEET (H)

0 2.5 5
SCALE IN FEET (V)

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DATE	11/8/2022			
PLOTTED BY	HollanRA			
DESIGNED BY	R. HOLLAND			
ENTERED BY	R. HOLLAND			
CHECKED BY	K. WILLIAMS			
PROJ. ENGR.	J. HEILMAN			
REGIONAL ADM.	-	REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
Y-12554		
CONTRACT NO.		LOCATION NO.
C1744		

PRELIMINARY
NOT FOR CONSTRUCTION

P.E. STAMP BOX DATE
P.E. STAMP BOX DATE

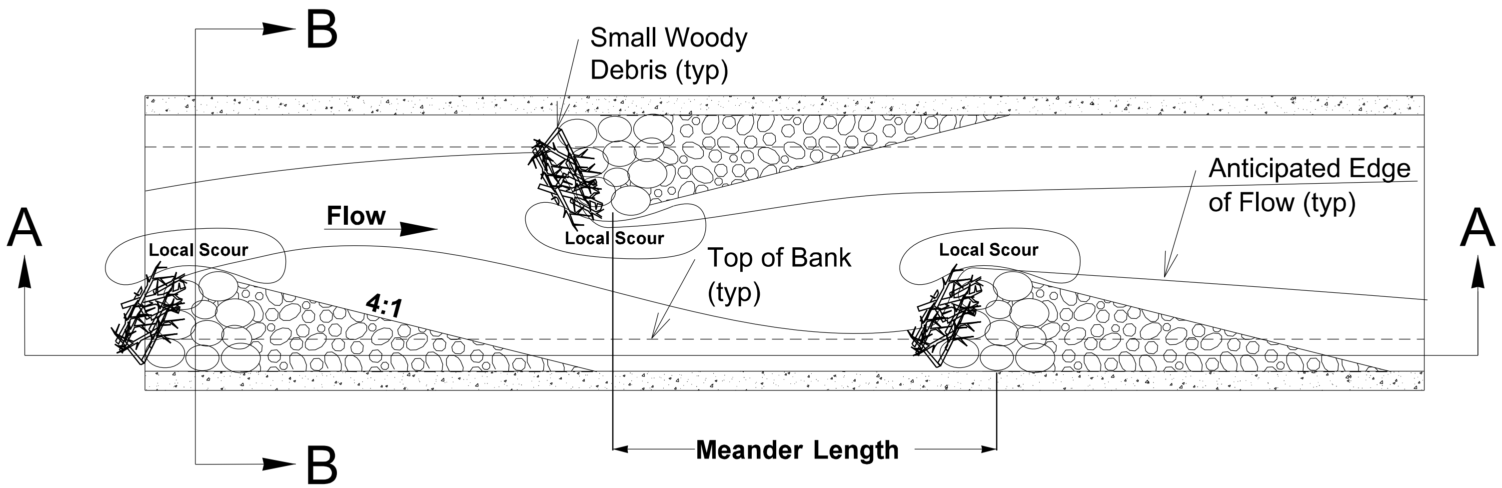
Washington State
Department of Transportation

SR 3 MILE POST 52.21
991744 JOHNSON CREEK TO LIBERTY BAY
FISH BARRIER REMOVAL

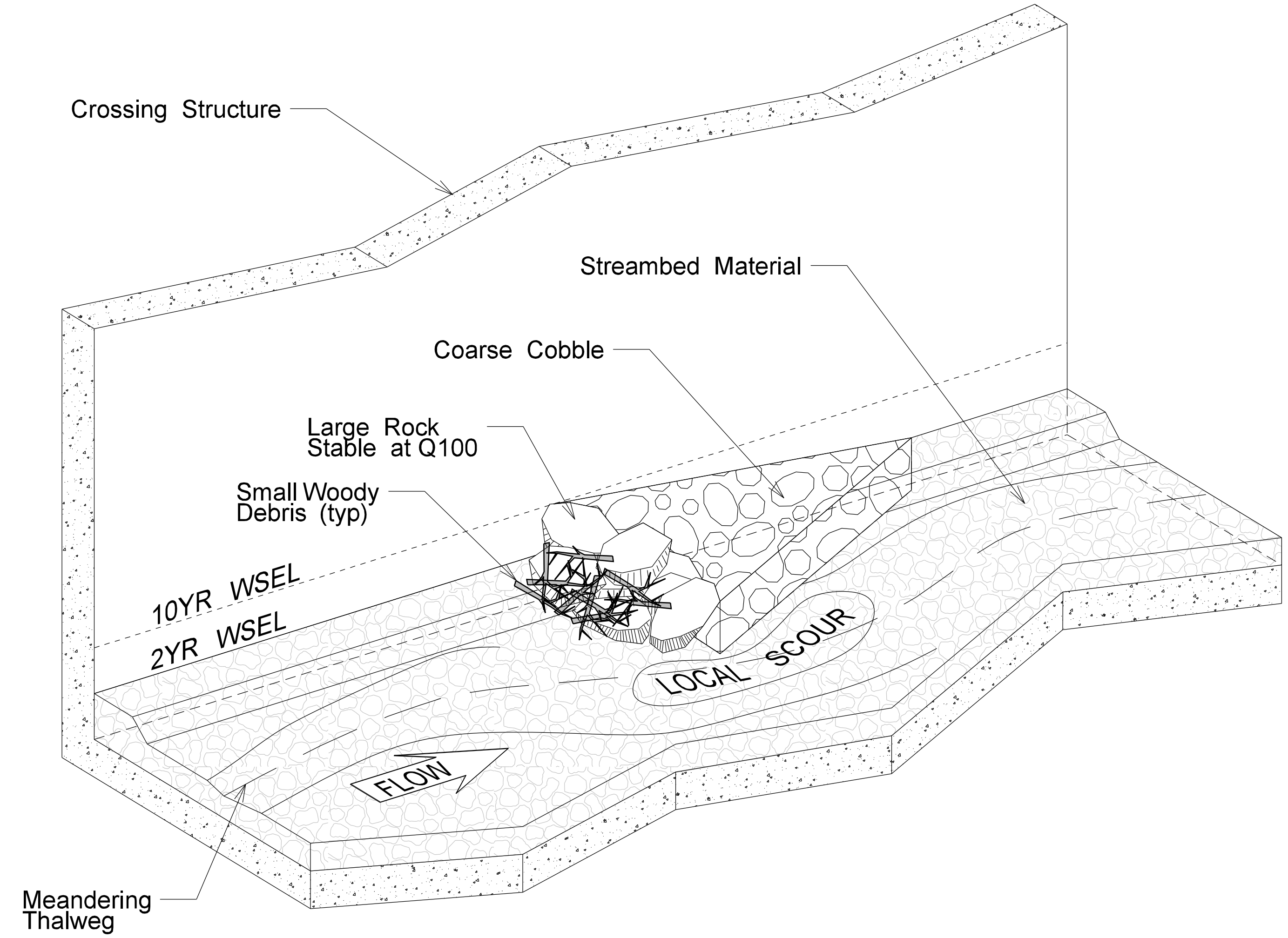
PROPOSED CROSS SECTION SHEET 2 OF 2

PLAN REF NO
CD2

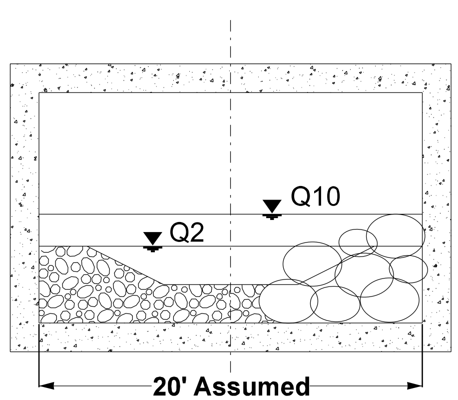
SHEET
6
OF
7
SHEETS



Plan View



Isometric View



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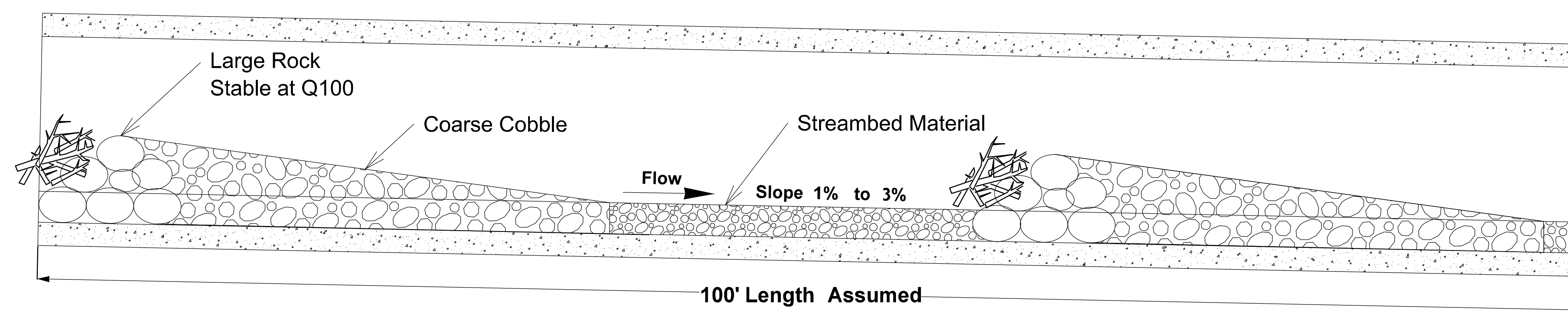

Section A-A

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DESIGNED BY	R. HOLLAND
ENTERED BY	R. HOLLAND
CHECKED BY	K. WILLIAMS
PROJ. ENGR.	J. HEILMAN
REGIONAL ADM.	-

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER Y-12554

CONTRACT NO. C1744 | LOCATION NO.

PRELIMINARY
NOT FOR CONSTRUCTION

P.E. STAMP BOX DATE | P.E. STAMP BOX DATE

Washington State
Department of Transportation

SR 3 MILE POST 52.21
991744 JOHNSON CREEK TO LIBERTY BAY
FISH BARRIER REMOVAL

STANDARD MEANDER BAR DETAIL

PLAN REF NO CD3

SHEET 7 OF 7 SHEETS

Appendix E: Manning's Calculations

Existing Channel Roughness

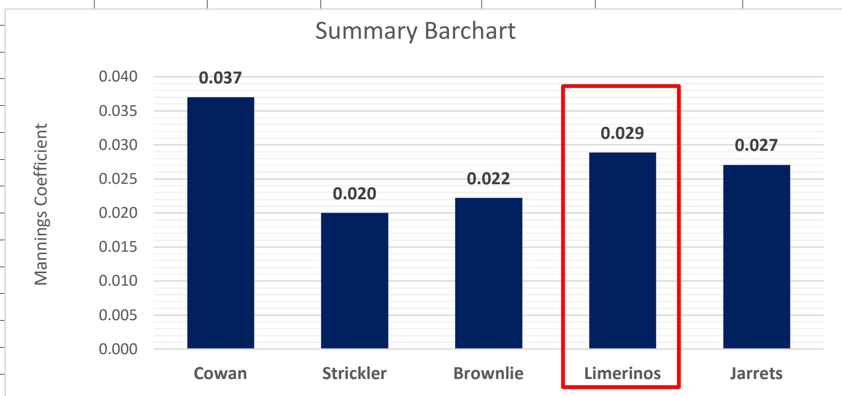
JOB TITLE:	SF Johnson Cr to Liberty Bay, ID 991744			BY:	J. Laundry, EIT		DATE:	7/15/2022	
SUBJECT:	Flow Resistance Determination			CHECKED:	T. Bedford, PE		Sheet # :	1 of 1	

Background:

Guide for Selecting Manning's Roughness Coefficient for Natural Channels and Flood Plains (USGS)

"Habitat Modeling" is in the scope.

Inputs					**Summary**		*6" Minus*	**4" Minus**	**2.5" Minus**
d50	12.7	mm	2, 3	1	Cowan	0.037	0.037	0.037	0.037
d16	2.54	mm	3	2	Strickler	0.020	0.020	0.020	0.020
d84	27.94	mm	3	3	Brownlie	0.022	0.032	0.030	0.029
Flow Area	6.06	sq. ft	4	4	Limerinos	0.029	0.056	0.042	0.038
Wetted Perimeter	6.58	ft	4	5	Jarrets	0.027	0.105	0.105	0.105
Hydraulic Radius	0.92	ft	3, 4						
WS Slope	0.001	ft/ft	3, 5						



1	**Source**	Cowan, 1956		
	Application	Sand bed streams...		
	Source	http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm		
	Equation	n = (nb+n1+n2+n3+n4) * m		
		Type	**Value**	**Notes**
		nb	0.031	
		n1	0.001	Correction factor for surface irregularities
		n2	0.001	Variation in shape and size of the channel cross section
		n3	0.002	Value for obstrucitons
		n4	0.002	Value for vegetation and flow conditions
		m	1.00	Correction factor for emandering of the channel
		n-value	0.037	

2	**Source**	Strickler Equation							
	Application	http://www.hydrology.bee.cornell.edu/BEE4730Handouts/ACE_Scobey_n.pdf							page 2
	Equation	$n = (0.034)d50^{1/6}$							

d50	n-value
ft	---
0.042	**0.020**

3	**Source**	Brownlie (from HEC-RAS Manual)							
	Application	Developed for sand bed streams and had two forms based on the flow regime, to account for changing bedform (form dr							
	Equation	$$n = \left(1.6940 * \left(\frac{R}{d_{50}}\right)^{0.1374} S^{0.1112}\,\sigma^{0.1605}\right) 0.034(d_{50})^{0.167}$$							

d16	d50	d84	Hydraulic Radius	S	sigma	n lower	n upper
ft	*ft*	*ft*	*ft*	*ft/ft*	*std dev*	*lower regime*	*lower regime*
0.01	0.04	0.09	0.92191569	0.00085385	1.33	0.025	0.020

4	**Source**	Limerinos	
	Application	Small gravel to medium sized boulders	
	Source	https://pubs.usgs.gov/wsp/2339/report.pdf	page 10
	Equation	$$n = \frac{\left(0.0926 * R^{\frac{1}{6}}\right)}{1.16 + 2.0 * \log\left(\frac{R}{D_{50}}\right)}$$	$n = \frac{(0.0926)R^{1/6}}{1.16+2.0\log(R/d84)}$

d84	Area	Wetted Perimeter	Hydraulic Radius	N-Value
ft	*sq. ft*	*ft*	*ft*	---
0.09	6.063887284	6.57748572	0.92	0.0289

5	**Source**	Jarrets, 1985
	Application	Steep Gradient Streams ($S_o > 0.01$)
	Source	https://pubs.usgs.gov/wri/1985/4004/report.pdf
	Equation	

Shallow Depth Applicability

$$\boxed{\frac{R}{D_{50}} < 5}$$

Jarrets, 1985

$$\boxed{n = 0.39 S_f^{0.38} R^{-0.16}}$$

R	D50	R/D50	Applicable?	WS Slope	Hydraulic Radius	N-Value
ft	*ft*	---	---	*ft/ft*	*ft*	---
0.9	0.04	22.13	**lot-Applicabl**	0.001	0.922	0.027

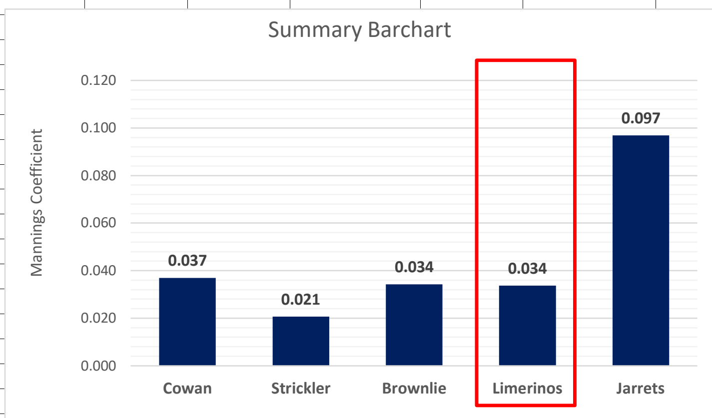
Proposed Channel Roughness

JOB TITLE:	SF Johnson Cr to Liberty Bay, ID 991744	BY:	J. Laundry, EIT	DATE:	11/22/2022
SUBJECT:	Flow Resistance Determination	CHECKED:	T. Bedford, PE	Sheet # :	1 of 1

Background:
Guide for Selecting Manning's Roughness Coefficient for Natural Channels and Flood Plains (USGS)
"Habitat Modeling" is in the scope.

Inputs				
d50	15.19	mm	2, 3	
d16	0.48	mm	3	From SBM
d84	55.59	mm	3	Grain Stress
Flow Area	9.91	sq. ft	4	From summary table
Wetted Perimeter	7.44	ft	4	From summary table
Hydraulic Radius	1.33	ft	3, 4	From summary table
WS Slope	0.0347	ft/ft	3, 5	From CAD

	Summary		***6" Minus***	**4" Minus**	**2.5" Minus**
1	Cowan	0.037	0.037	0.037	0.037
2	Strickler	0.021	0.020	0.020	0.020
3	Brownlie	0.034	0.032	0.030	0.029
4	Limerinos	0.034	0.056	0.042	0.038
5	Jarrets	0.097	0.105	0.105	0.105



1	**Source**	Cowan, 1956
	Application	Sand bed streams…
	Source	http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm
	Equation	n = (nb+n1+n2+n3+n4) * m

Type	**Value**	**Notes**
nb	0.031	
n1	0.001	Correction factor for surface irregularities
n2	0.001	Variation in shape and size of the channel cross section
n3	0.002	Value for obstrucitons
n4	0.002	Value for vegetation and flow conditions
m	1.00	Correction factor for emandering of the channel
n-value	0.037	

2

Source Strickler Equation

Application http://www.hydrology.bee.cornell.edu/BEE4730Handouts/ACE_Scobey_n.pdf page 2

Equation

n= (0.034)d50 $^{1/6}$

d50	n-value
ft	---
0.050	**0.021**

3

Source Brownlie (from HEC-RAS Manual)

Application Developed for sand bed streams and had two forms based on the flow regime, to account for changing bedform (form drag) under changing f

Equation

$$n = \left(1.6940 * \left(\frac{R}{d_{50}}\right)^{0.1374} S^{0.1112} \sigma^{0.1605}\right) 0.034(d_{50})^{0.167}$$

d16	d50	d84	Hydraulic Radius	S	sigma	n lower	n upper
ft	*ft*	*ft*	*ft*	*ft/ft*	*std dev*	*lower regime*	*lower regime*
0.00	0.05	0.18	1.331989247	0.0347	2.26	0.043	0.025

4

Source Limerinos

Application Small gravel to medium sized boulders

Source https://pubs.usgs.gov/wsp/2339/report.pdf page 10

Equation

$$n = \frac{\left(0.0926 * R^{\frac{1}{6}}\right)}{1.16 + 2.0 * \log\left(\frac{R}{D_{50}}\right)}$$

n= (0.0926)R $^{1/6}$
1.16+2.0log(R/d84)

d84	Area	Wetted Perimeter	Hydraulic Radius	N-Value
ft	*sq. ft*	*ft*	*ft*	---
0.18	9.91	7.44	1.33	0.0336

5

Source Jarrets, 1985

Application Steep Gradient Streams (S_o > 0.01)

Source https://pubs.usgs.gov/wri/1985/4004/report.pdf

Equation

Shallow Depth Applicability

$$\frac{R}{D_{50}} < 5$$

Jarrets, 1985

$$n = 0.39 S_f^{0.38} R^{-0.16}$$

R	D50	R/D50	Applicable?	WS Slope	Hydraulic Radius	N-Value
ft	*ft*	---	---	*ft/ft*	*ft*	---
1.3	0.05	26.73	**Iot-Applicabl**	0.035	1.332	0.097

Proposed Meander Bars and Coarse Bands Roughness

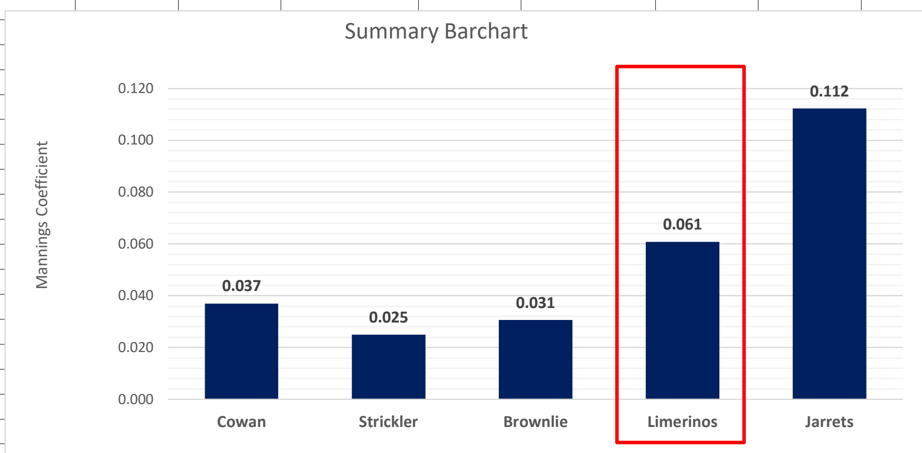
JOB TITLE:	SF Johnson Cr to Liberty Bay, ID 991744	BY:	J. Laundry, EIT	DATE:	11/22/2022
SUBJECT:	Flow Resistance Determination	CHECKED:	T. Bedford, PE	Sheet # :	1 of 1

Background:
Guide for Selecting Manning's Roughness Coefficient for Natural Channels and Flood Plains (USGS)
"Habitat Modeling" is in the scope.

Inputs				
d50	47.5	mm	2, 3	
d16	16.7	mm	3	From SBM
d84	126.3	mm	3	Grain Stress
Flow Area	4.17	sq. ft	4	From summary table
Wetted Perimeter	7.90	ft	4	From summary table
Hydraulic Radius	0.53	ft	3, 4	From summary table
WS Slope	0.0347	ft/ft	3, 5	From CAD

	Summary		***6" Minus***	**4" Minus**	**2.5" Minus**
1	Cowan	0.037	0.037	0.037	0.037
2	Strickler	0.025	0.020	0.020	0.020
3	Brownlie	0.031	0.032	0.030	0.029
4	Limerinos	0.061	0.056	0.042	0.038
5	Jarrets	0.112	0.105	0.105	0.105

*Meander Bars will have an additional 0.04 roughness to account for increased height



1	**Source**	Cowan, 1956
	Application	Sand bed streams…
	Source	http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm
	Equation	n = (nb+n1+n2+n3+n4) * m

Type	**Value**	**Notes**
nb	0.031	
n1	0.001	Correction factor for surface irregularities
n2	0.001	Variation in shape and size of the channel cross section
n3	0.002	Value for obstrucitons
n4	0.002	Value for vegetation and flow conditions
m	1.00	Correction factor for emandering of the channel
n-value	0.037	

2	**Source**	Strickler Equation										
	Application	http://www.hydrology.bee.cornell.edu/BEE4730Handouts/ACE_Scobey_n.pdf							page 2			
	Equation	$n = (0.034)d50^{1/6}$										

d50	n-value
ft	---
0.156	**0.025**

3	**Source**	Brownlie (from HEC-RAS Manual)										
	Application	Developed for sand bed streams and had two forms based on the flow regime, to account for changing bedform (form drag) under changing flo										
	Equation											

$$n = \left(1.6940 * \left(\frac{R}{d_{50}}\right)^{0.1374} S^{0.1112} \sigma^{0.1605}\right) 0.034(d_{50})^{0.167}$$

d16	d50	d84	Hydraulic Radius	S	sigma	n lower	n upper
ft	*ft*	*ft*	*ft*	*ft/ft*	*std dev*	*lower regime*	*lower regime*
0.05	0.16	0.41	0.527848101	0.0347	1.35	0.036	0.025

4	**Source**	Limerinos										
	Application	Small gravel to medium sized boulders										
	Source	https://pubs.usgs.gov/wsp/2339/report.pdf				page 10						
	Equation											

$$n = \frac{\left(0.0926 * R^{\frac{1}{6}}\right)}{1.16 + 2.0 * \log\left(\frac{R}{D_{50}}\right)}$$

$$n = \frac{(0.0926)R^{1/6}}{1.16+2.0\log(R/d84)}$$

d84	Area	Wetted Perimeter	Hydraulic Radius	N-Value
ft	*sq. ft*	*ft*	*ft*	---
0.41	4.17	7.9	0.53	0.0608

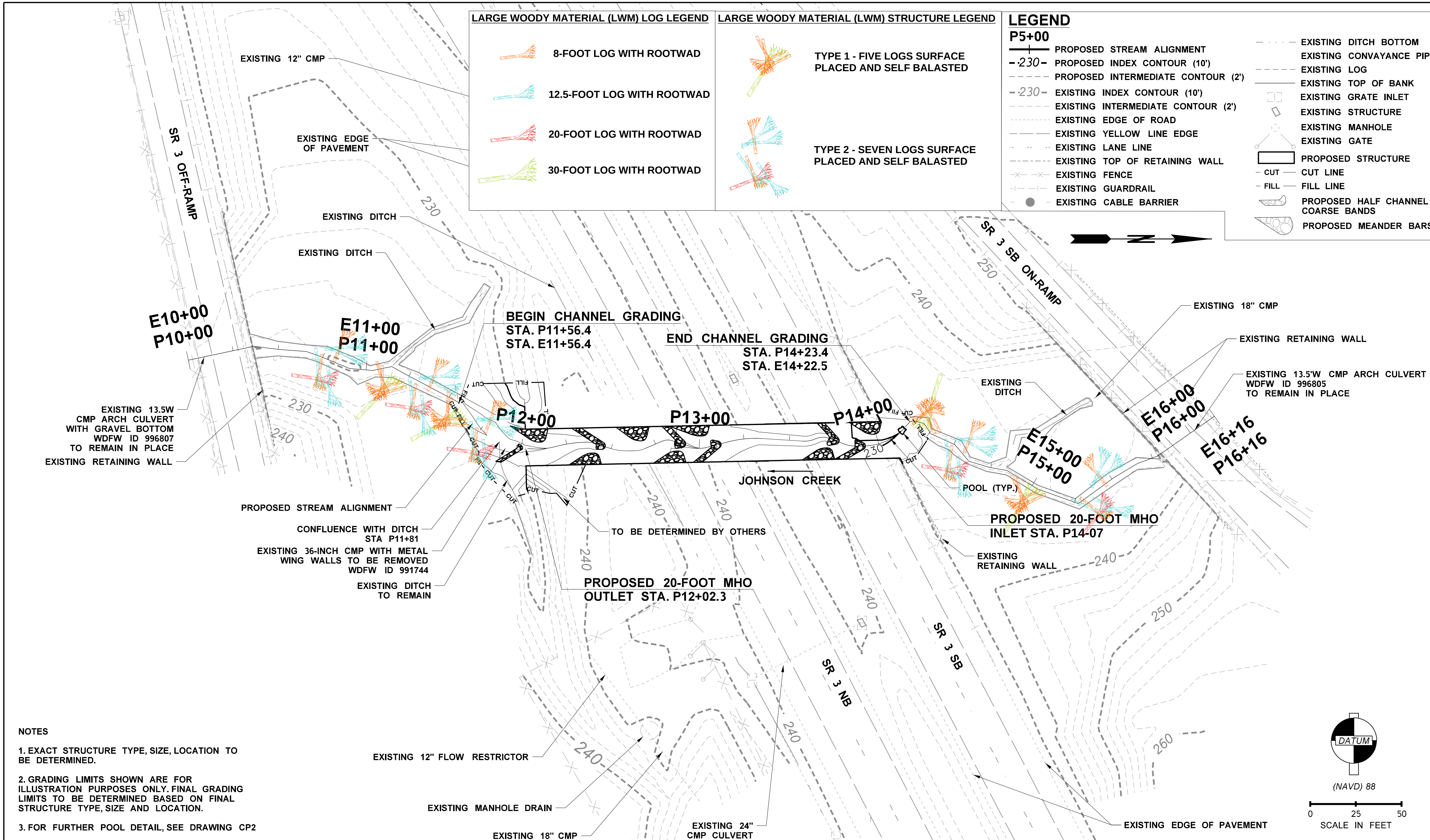
5	**Source**	Jarrets, 1985										
	Application	Steep Gradient Streams ($S_o > 0.01$)										
	Source	https://pubs.usgs.gov/wri/1985/4004/report.pdf										
	Equation											
	Shallow Depth Applicability				*Jarrets, 1985*							

$$\frac{R}{D_{50}} < 5$$

$$n = 0.39 S_f^{0.38} R^{-0.16}$$

R	D50	R/D50	Applicable?	WS Slope	Hydraulic Radius	N-Value
ft	*ft*	---	---	*ft/ft*	*ft*	---
0.5	0.16	3.39	**Applies**	0.035	0.528	0.112

Appendix F: Large Woody Material Calculations



NOTES

1. EXACT STRUCTURE TYPE, SIZE, LOCATION TO BE DETERMINED.

2. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL GRADING LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE TYPE, SIZE AND LOCATION.

3. FOR FURTHER POOL DETAIL, SEE DRAWING CP2

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DESIGNED BY	R. HOLLAND
ENTERED BY	R. HOLLAND
CHECKED BY	K. WILLIAMS
PROJ. ENGR.	J. HEILMAN
REGIONAL ADM.	-

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
Y-12554		
CONTRACT NO.	LOCATION NO.	
C1744		

PRELIMINARY
NOT FOR CONSTRUCTION

P.E. STAMP BOX DATE
P.E. STAMP BOX DATE

Washington State
Department of Transportation

SR 3 MILE POST 52.21
991744 JOHNSON CREEK TO LIBERTY BAY
FISH BARRIER REMOVAL

PROPOSED STREAM PLAN

PLAN REF NO
CR1

SHEET 3 OF 7 SHEETS

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	*SR 3, MP 52.21*	**Key piece volume**	***1.310***	*yd3*	
Stream name	*Johnson Creek*	**Key piece/ft**	***0.0335***	*per ft stream*	yes
length of regrade[a]	*267* ft	**Total wood vol./ft**	***0.3948***	*yd3/ft stream*	no
Bankfull width	*7.5* ft	**Total LWM**[c] **pieces/ft stream**	***0.1159***	*per ft stream*	
Habitat zone[b]	*Western WA*				

Taper coeff.	-0.01554
LF_{rw}	1.5
H_{dbh}	4.5

Log type	*Diameter at midpoint (ft)*	*Length(ft)*[d]	*Volume (yd^3/log)*[d]	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd^3)*
A	2.39	*30*	4.98	**yes**	yes	4	19.94
B	1.70	*20*	1.68	**yes**	yes	5	8.41
C	1.25	*12.5*	0.57	**yes**	no	20	11.36
D	0.94	*8*	0.21	**yes**	no	26	5.35
E			0.00	**yes**			0.00
F			0.00	**no**			0.00
G			0.00	**no**			0.00
H			0.00				0.00
I			0.00				0.00
J			0.00				0.00
K			0.00				0.00
L			0.00				0.00
M			0.00				0.00
N			0.00				0.00
O			0.00				0.00
P			0.00				0.00

DBH based on mid point diameter (ft)	$D_{root\ collar\ (ft)}$	L/2-Lrw (ft)
2.50	2.57	11.415
1.75	1.82	7.45
1.25	1.32	4.375
0.91	0.98	2.59
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0

Log volume for stability calcs (yd^3, per log)	
rootwad	bole
2.07	4.39
0.74	1.47
0.30	0.48
0.13	0.17
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	9	55	45.1
Targets	**9**	**31**	**105.4**
	on target	surplus	deficit

[a] **includes length through crossing, regardless of structure type**

[b] **choose one of the following Forest Regions in the drop-down menu (if in doubt ask HQ Biology). See also the Forest Region tab for additional information**

Western Washington lowl	(generally <4,200 ft. in elevation west of the Cascade Crest)
Alpine	(generally > 4,200 ft. in elevation and down to ~3,700 ft. in elevation east of the Cascade crest)
Douglas fir-Ponderosa pin	(mainly east slope Cascades below 3,700 ft. elevation)

[c] **LWM (Large Woody Material), also known as LWD (Large Woody Debris) is defined as a piece of wood at least 10 cm (4") diam. X 2 m (6ft) long (Fox 2001).**

[d] **includes rootwad if present**

Key piece volume

BFW class (ft)	volume (yd3)
0-16	1.31
17-33	3.28
34-49	7.86
50-66	11.79
67-98	12.77
99-164	13.76
165-328	14.08

adapted from Fox and Bolton (2007), Table 5

Key Piece density lookup table

Habitat zone	BFW class (feet)	75th percentile (yd3/ft stream)
Western WA	0-33	0.0335
	34-328	0.0122
Alpine	0-49	0.0122
	50-164	0.0030
Douglas Fir/Pond. Pine (much of eastern WA)	0-98	0.0061

adapted from Fox and Bolton (2007), Table 4

Total Wood Volume lookup table

Habitat zone	BFW class (feet)	75th percentile (yd3/ft stream)
Western WA	0-98	0.3948
	99-328	1.2641
Alpine	0-10	0.0399
	11-164	0.1196
Douglas Fir/Pond. Pine	0-98	0.0598

adapted from Fox and Bolton (2007), Table 4

Number of LWM pieces lookup table

Habitat zone	BFW class (feet)	75th percentile (per/ft stream)
Western WA	0-20	0.1159
	21-98	0.1921
	99-328	0.6341
Alpine	0-10	0.0854
	11-98	0.1707
	99-164	0.1921
Douglas Fir/Pond. Pine	0-20	0.0884
	21-98	0.1067

adapted from Fox and Bolton (2007), Table 4

Appendix G: Future Projections for Climate-Adapted Culvert Design

Future Projections for Climate-Adapted Culvert Design

Project Name: 991744

Stream Name: SF Johnson Cr

Drainage Area: 389 ac

Projected mean percent change in bankfull flow:

2040s: 13.3%

2080s: 16.1%

Projected mean percent change in bankfull width:

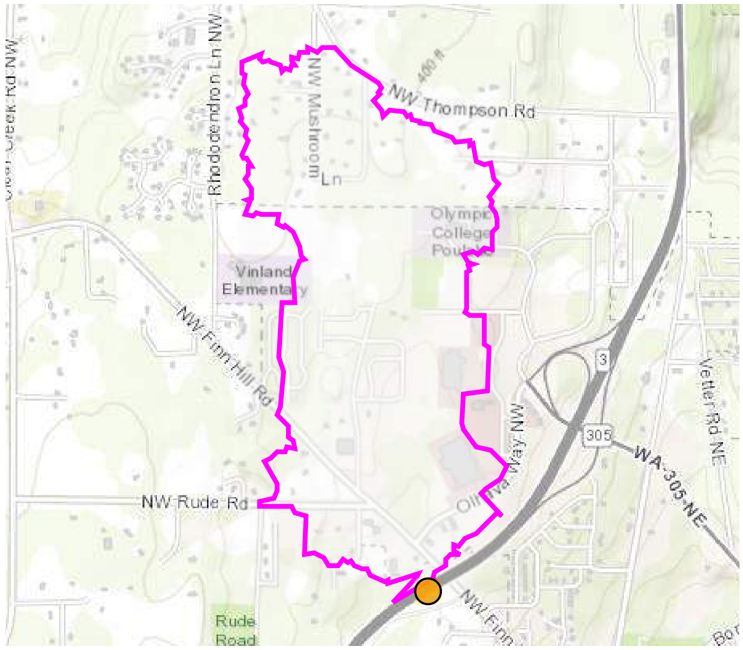
2040s: 6.4%

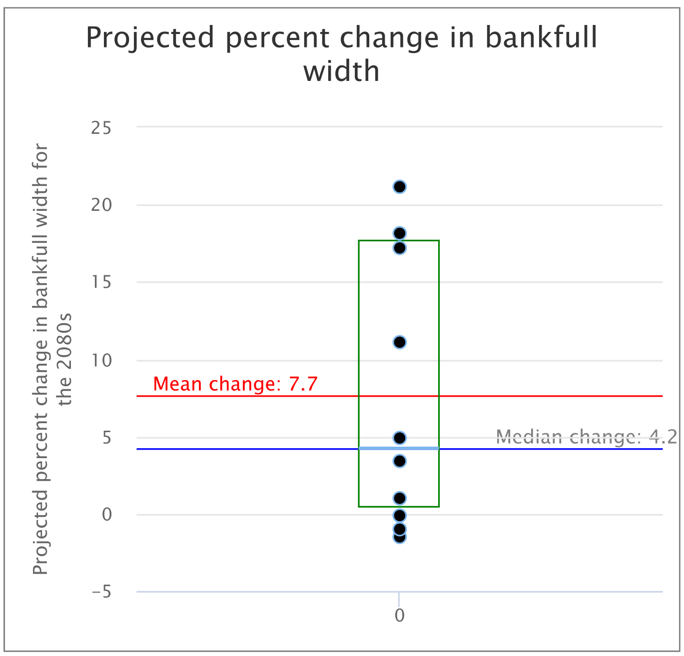
2080s: 7.7%

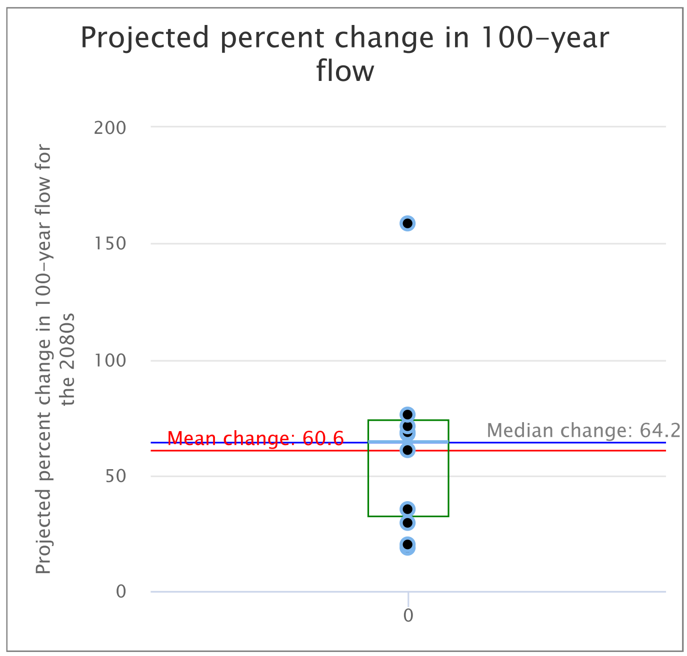
Projected mean percent change in 100-year flood:

2040s: 42.9%

2080s: 60.6%







Black dots are projections from 10 separate models

Appendix H: SRH-2D Model Results

Figure List

Plan View Results – Existing Conditions

1 Existing Conditions – Q2 Water Surface Elevation (ft, NAVD 88)
2 Existing Conditions – Q100 Water Surface Elevation (ft, NAVD 88)
3 Existing Conditions – Q500 Water Surface Elevation (ft, NAVD 88)
4 Existing Conditions – Q2 Depth (ft)
5 Existing Conditions – Q100 Depth (ft)
6 Existing Conditions – Q500 Depth (ft)
7 Existing Conditions – Q2 Velocity Magnitude (ft/s)
8 Existing Conditions – Q100 Velocity Magnitude (ft/s)
9 Existing Conditions – Q500 Velocity Magnitude (ft/s)
10 Existing Conditions – Q2 Shear Stress (psf)
11 Existing Conditions – Q100 Shear Stress (psf)
12 Existing Conditions – Q500 Shear Stress (psf)

Plan View Results – Natural Conditions

13 Natural Conditions – Q2 Water Surface Elevation (ft, NAVD 88)
14 Natural Conditions – Q100 Water Surface Elevation (ft, NAVD 88)
15 Natural Conditions – Q500 Water Surface Elevation (ft, NAVD 88)
16 Natural Conditions – Q2 Depth (ft)
17 Natural Conditions – Q100 Depth (ft)
18 Natural Conditions – Q500 Depth (ft)
19 Natural Conditions – Q2 Velocity Magnitude (ft/s)
20 Natural Conditions – Q100 Velocity Magnitude (ft/s)
21 Natural Conditions – Q500 Velocity Magnitude (ft/s)
22 Natural Conditions – Q2 Shear Stress (psf)
23 Natural Conditions – Q100 Shear Stress (psf)
24 Natural Conditions – Q500 Shear Stress (psf)

Plan View Results – Proposed Conditions

25 Proposed Conditions – Q2 Water Surface Elevation (ft, NAVD 88)
26 Proposed Conditions – Q100 Water Surface Elevation (ft, NAVD 88)
27 Proposed Conditions – Q500 Water Surface Elevation (ft, NAVD 88))
28 Proposed Conditions – 2080 Projected Q100 Water Surface Elevation (ft, NAVD 88)
29 Proposed Conditions – Q2 Depth (ft)
30 Proposed Conditions – Q100 Depth (ft)

31 Proposed Conditions – Q500 Depth (ft)
32 Proposed Conditions –Projected 2080 Q100 Depth (ft)
33 Proposed Conditions – Q2 Velocity Magnitude (ft/s)
34 Proposed Conditions – Q100 Velocity Magnitude (ft/s)
35 Proposed Conditions – Q500 Velocity Magnitude (ft/s)
36 Proposed Conditions –Projected 2080 Q100 Velocity Magnitude (ft/s)
37 Proposed Conditions – Q2 Shear Stress (psf)
38 Proposed Conditions – Q100 Shear Stress (psf)
39 Proposed Conditions – Q500 Shear Stress (psf)
40 Proposed Conditions –Projected 2080 Shear Stress (psf)

Longitudinal Profile Results

41 Existing Conditions - Longitudinal Profile – Water Surface Elevation (ft, NAVD 88)
42 Natural Conditions - Longitudinal Profile – Water Surface Elevation (ft, NAVD 88)
43 Proposed Conditions - Longitudinal Profile – Water Surface Elevation (ft, NAVD 88)

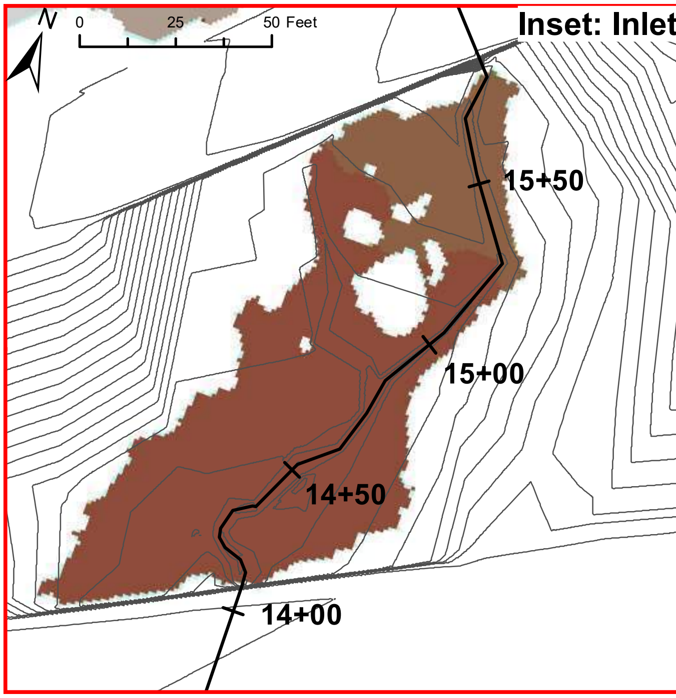
Cross-Section Results

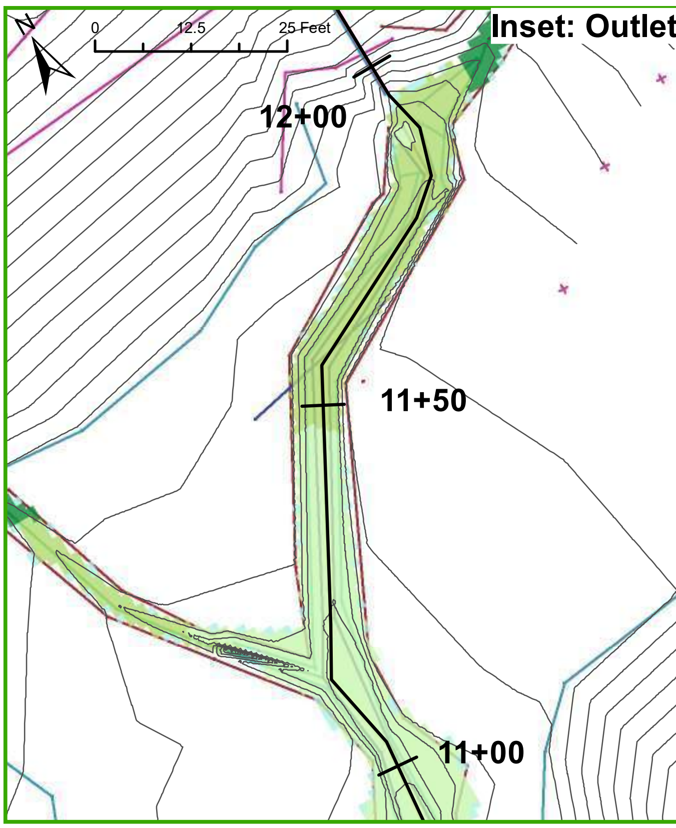
44 Existing Conditions – Cross Section 8 at STA 14+98
44 Natural Conditions – Cross Section 8 at STA 14+98
45 Proposed Conditions – Cross Section 8 at STA 14+99
45 Existing Conditions – Cross Section 6 at STA 14+68
46 Natural Conditions – Cross Section 6 at STA 14+68
46 Proposed Conditions – Cross Section 6 at STA 14+69
47 Existing Conditions – Cross Section 5 at STA 14+64
47 Natural Conditions – Cross Section 5 at STA 14+64
48 Proposed Conditions – Cross Section 5 at STA 14+65
48 Existing Conditions – Cross Section 4 at STA 14+30
49 Natural Conditions – Cross Section 4 at STA 14+30
49 Proposed Conditions – Cross Section 4 at STA 14+31
50 Proposed Conditions – Cross Section D at STA 13+90
50 Proposed Conditions – Cross Section C at STA 13+38
51 Proposed Conditions – Cross Section B at STA 12+99
51 Proposed Conditions – Cross Section A at STA 12+45
52 Existing Conditions – Cross Section 3 at STA 11+12
52 Natural Conditions – Cross Section 3 at STA 11+12
53 Proposed Conditions – Cross Section 3 at STA 11+12
53 Existing Conditions – Cross Section 2 at STA 11+27
54 Natural Conditions – Cross Section 2 at STA 11+27
54 Proposed Conditions – Cross Section 2 at STA 11+27

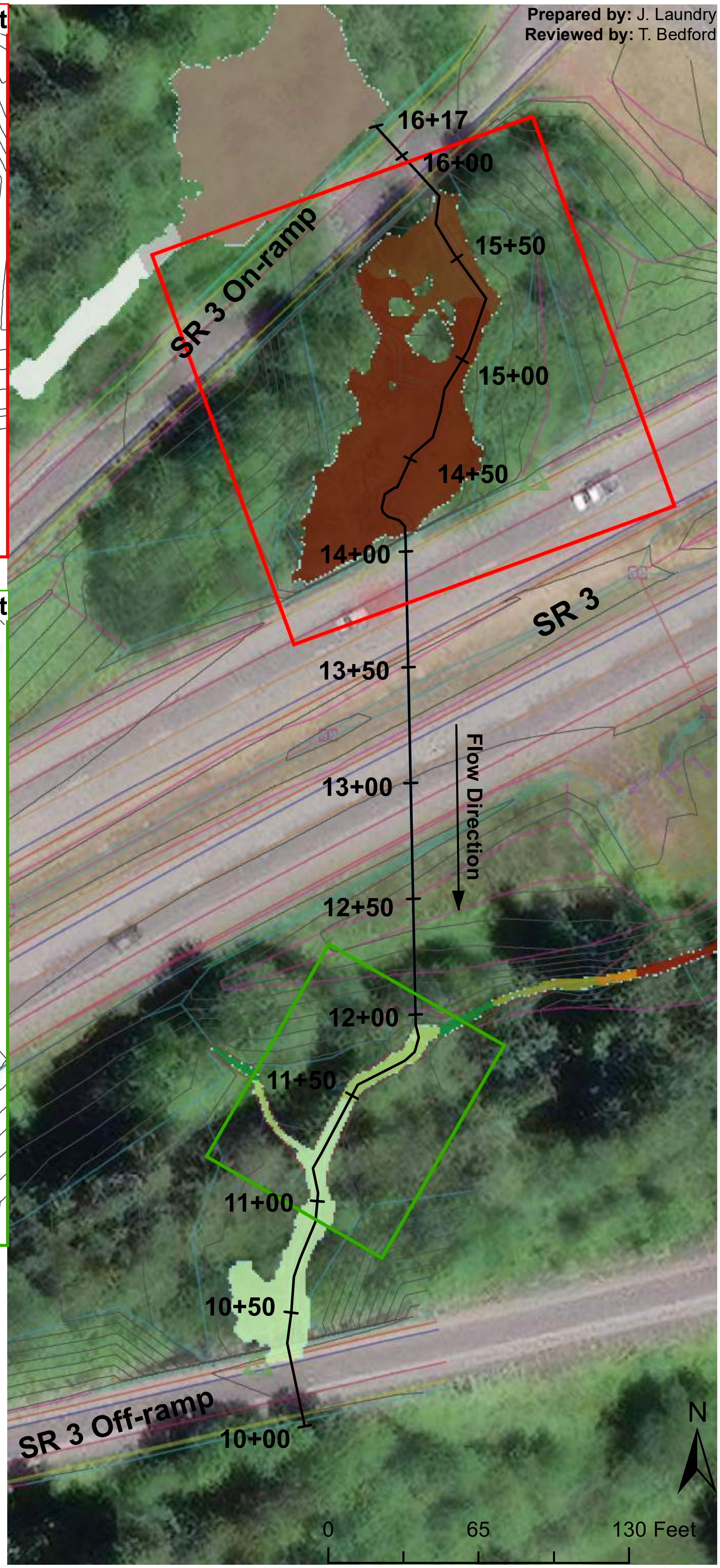
55 Existing Conditions – Cross Section 1 at STA 10+89
55 Natural Conditions – Cross Section 1 at STA 10+89
56 Proposed Conditions – Cross Section 1 at STA 10+89

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

Existing Conditions, 2yr Water Surface Elevation

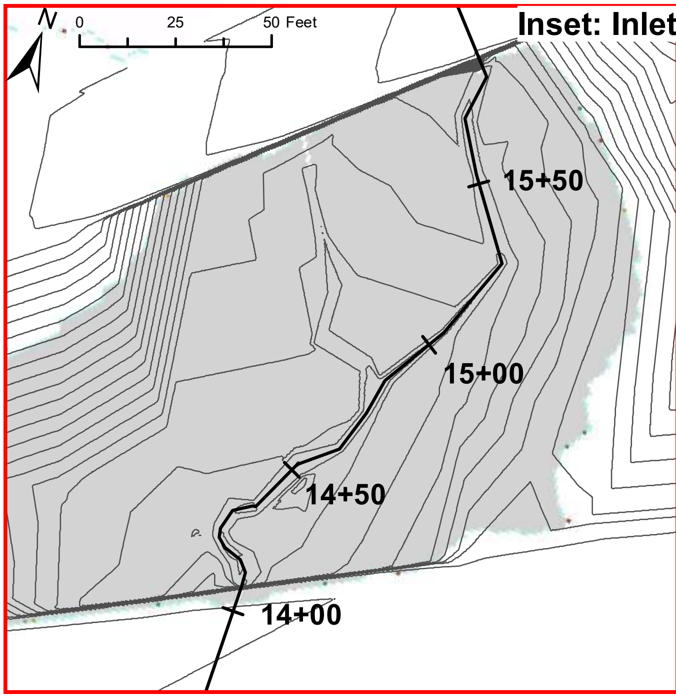
Water Surface Elevation (ft, NAVD '88)

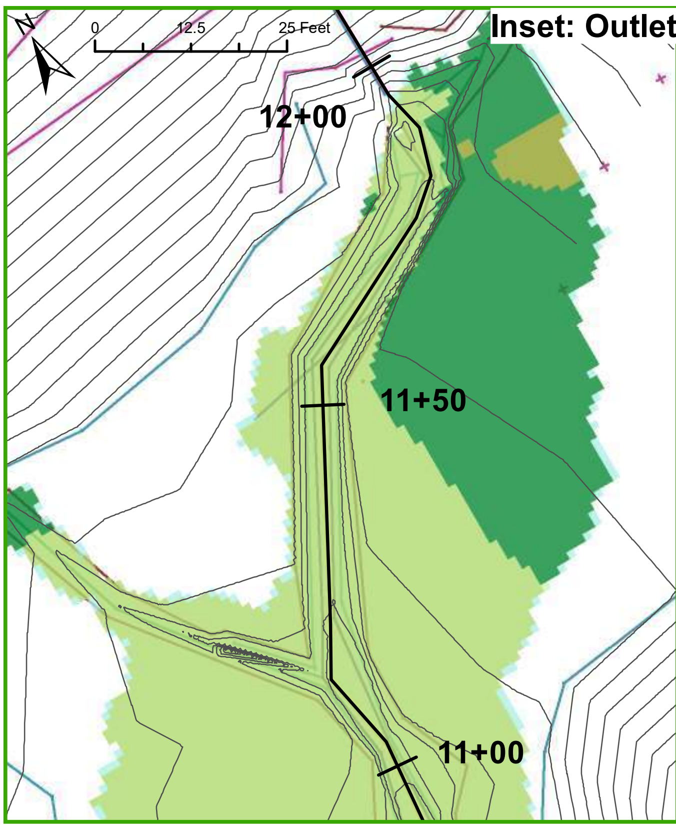
- < 221
- 221.0 - 223
- 223.0 - 225
- 225.0 - 227
- 227.0 - 229
- 229.0 - 231
- 231.0 - 233
- 233.0 - 235
- 235.0 - 237
- 237.0 - 239
- 239.0 - 241
- > 241

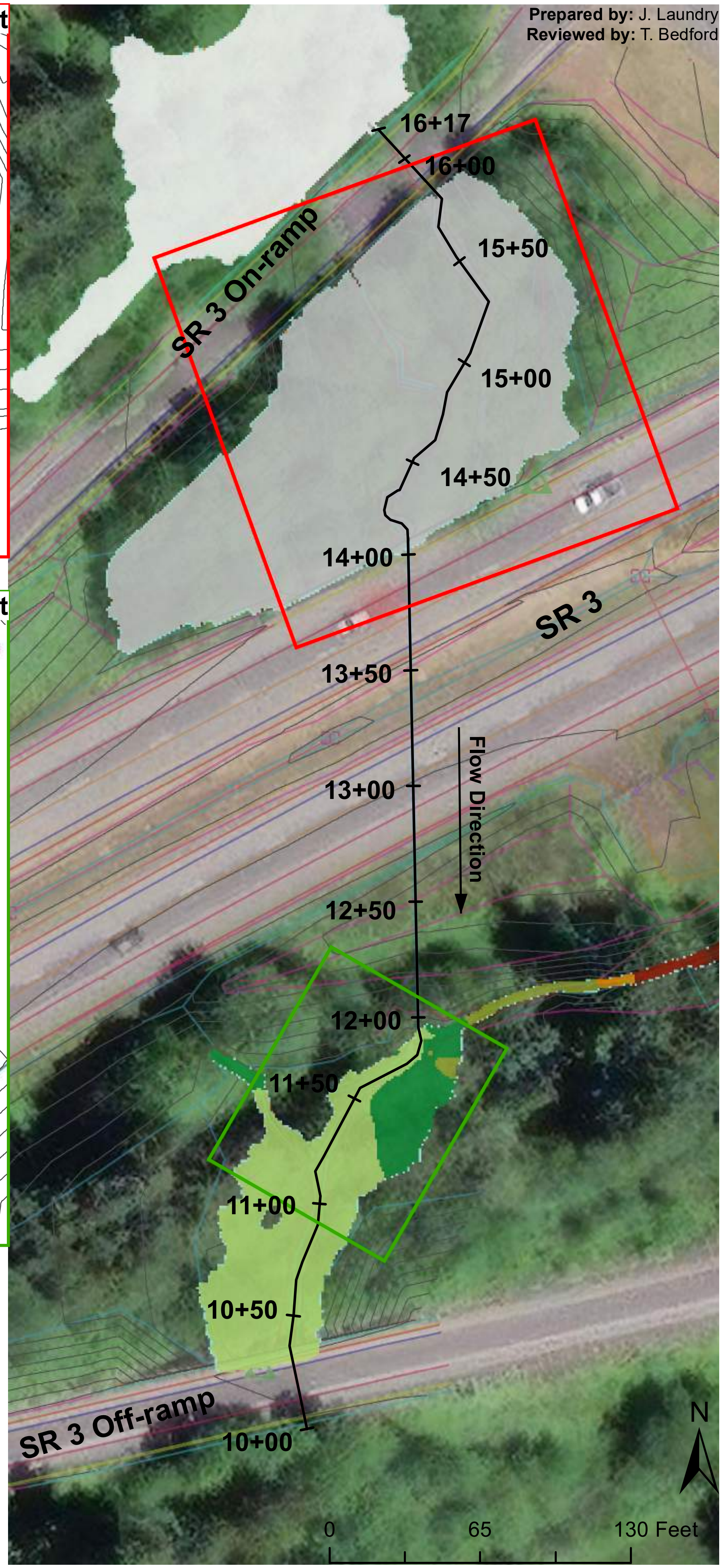
Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs

Prepared by: J. Laundry
Reviewed by: T. Bedford







*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

Existing Conditions, 100yr Water Surface Elevation

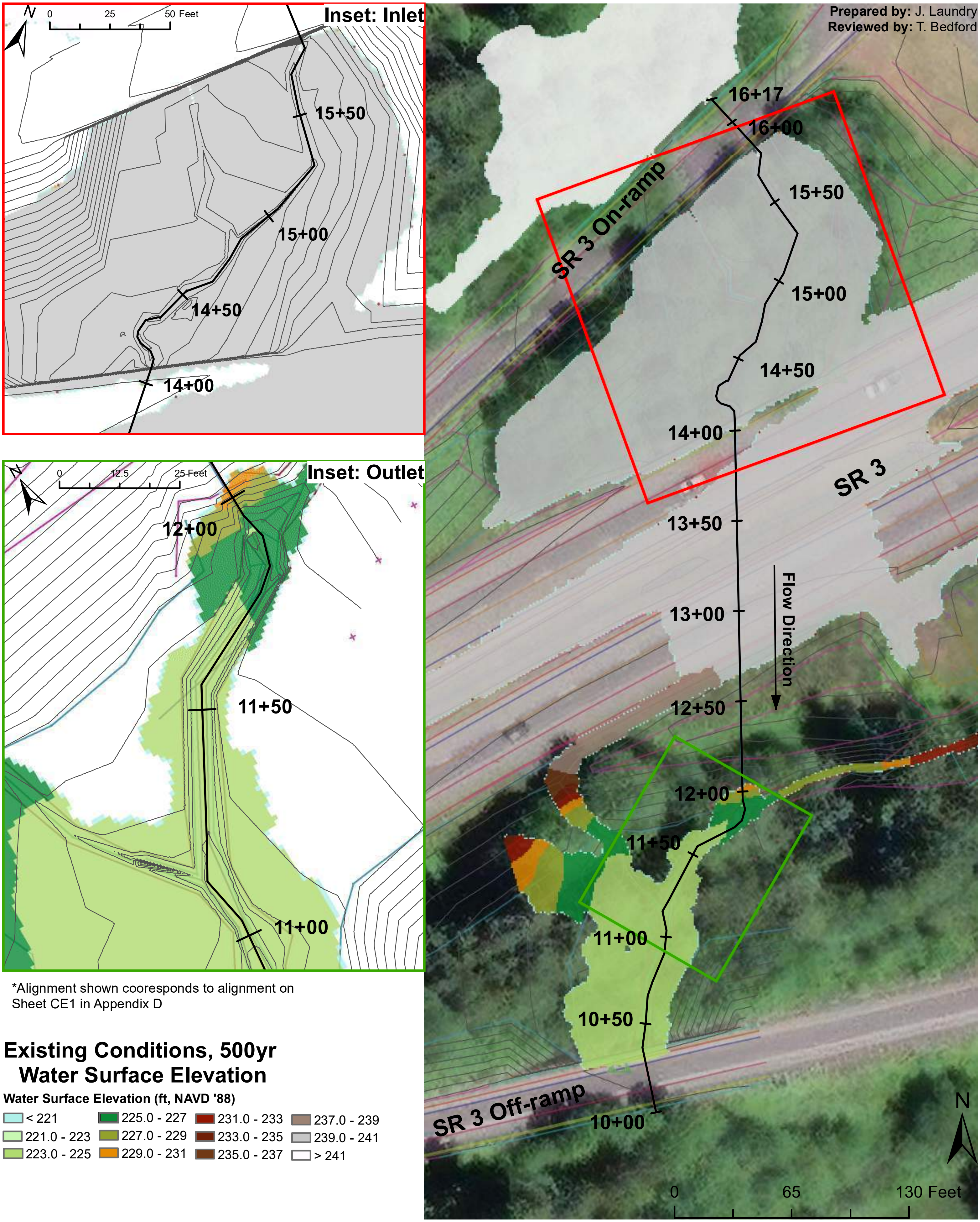
Water Surface Elevation (ft, NAVD '88)

< 221	225.0 - 227	231.0 - 233	237.0 - 239
221.0 - 223	227.0 - 229	233.0 - 235	239.0 - 241
223.0 - 225	229.0 - 231	235.0 - 237	> 241

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs

Prepared by: J. Laundry
Reviewed by: T. Bedford



*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

Existing Conditions, 500yr Water Surface Elevation

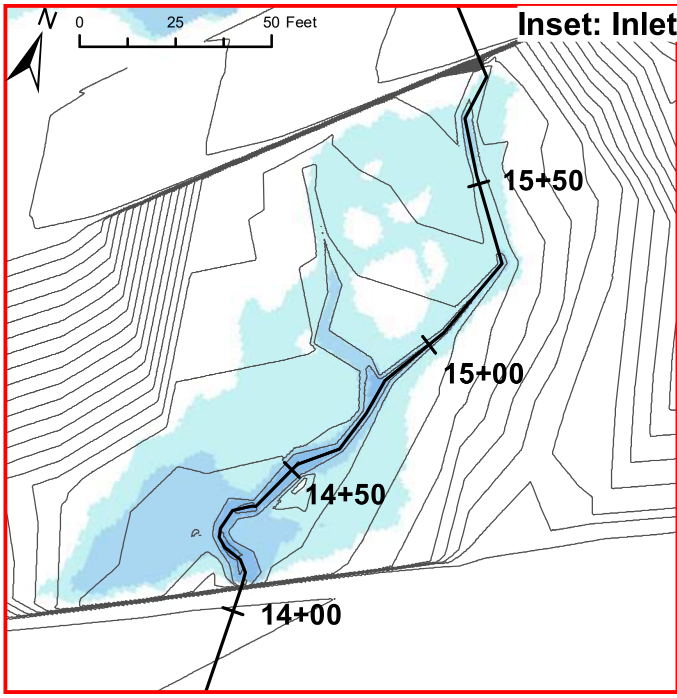
Water Surface Elevation (ft, NAVD '88)

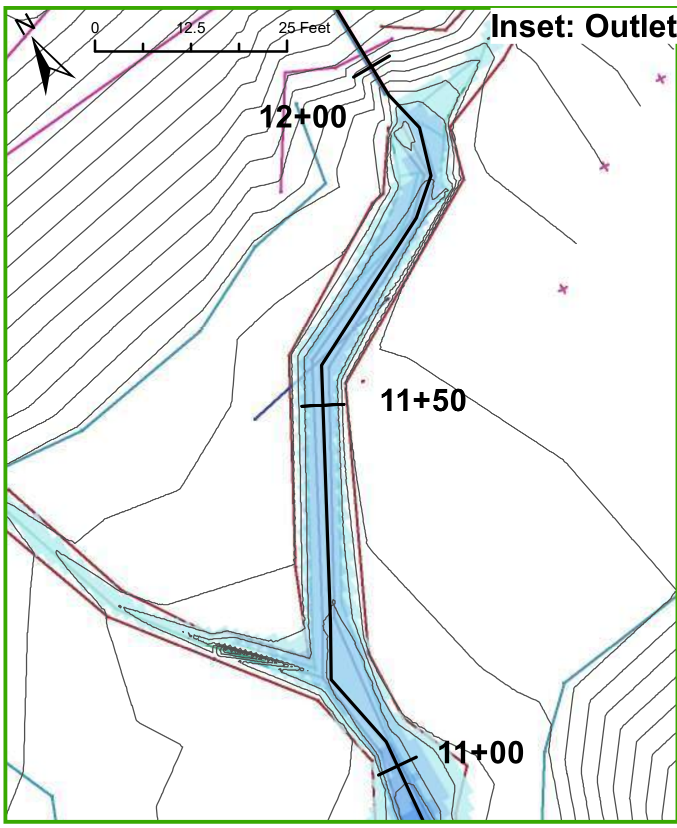
- < 221
- 221.0 - 223
- 223.0 - 225
- 225.0 - 227
- 227.0 - 229
- 229.0 - 231
- 231.0 - 233
- 233.0 - 235
- 235.0 - 237
- 237.0 - 239
- 239.0 - 241
- > 241

WSDOT OLYMPIC REGION GEC

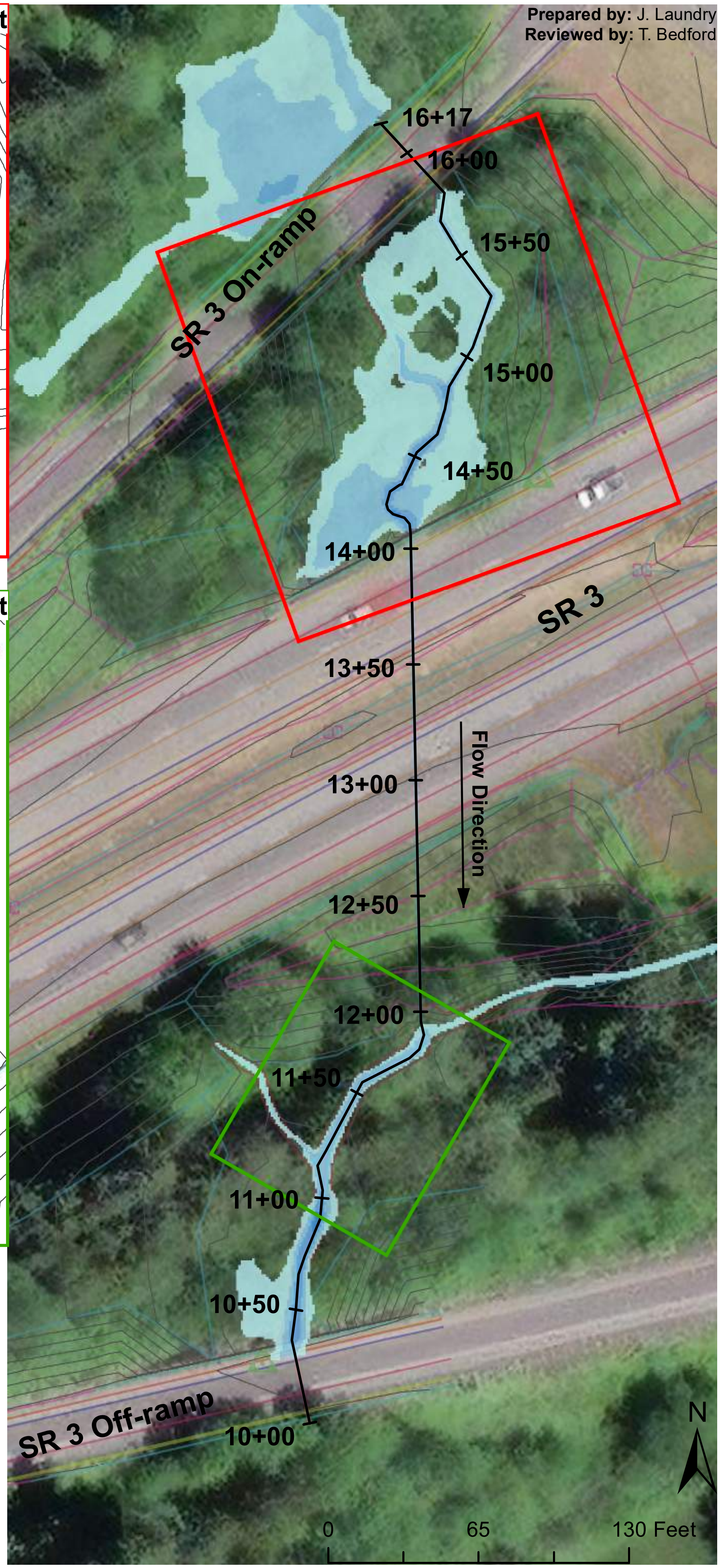
Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs





*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D



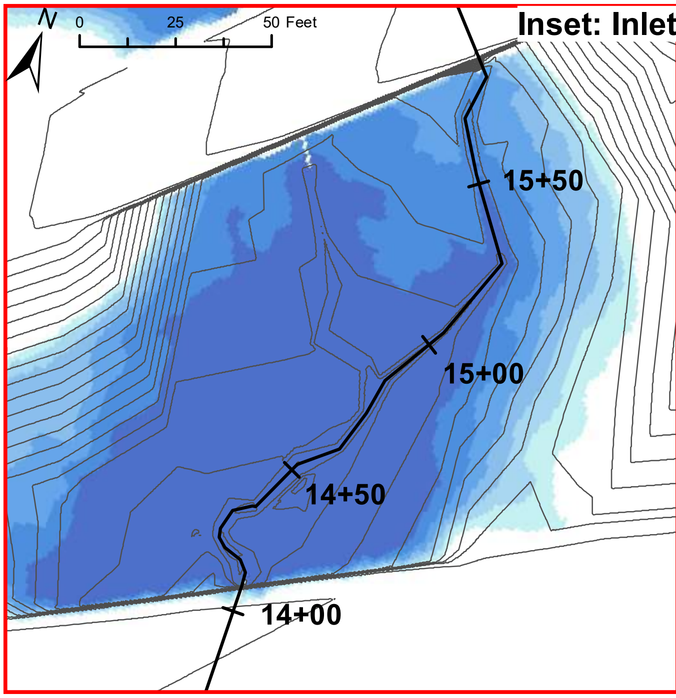
Existing Conditions, 2yr Depth

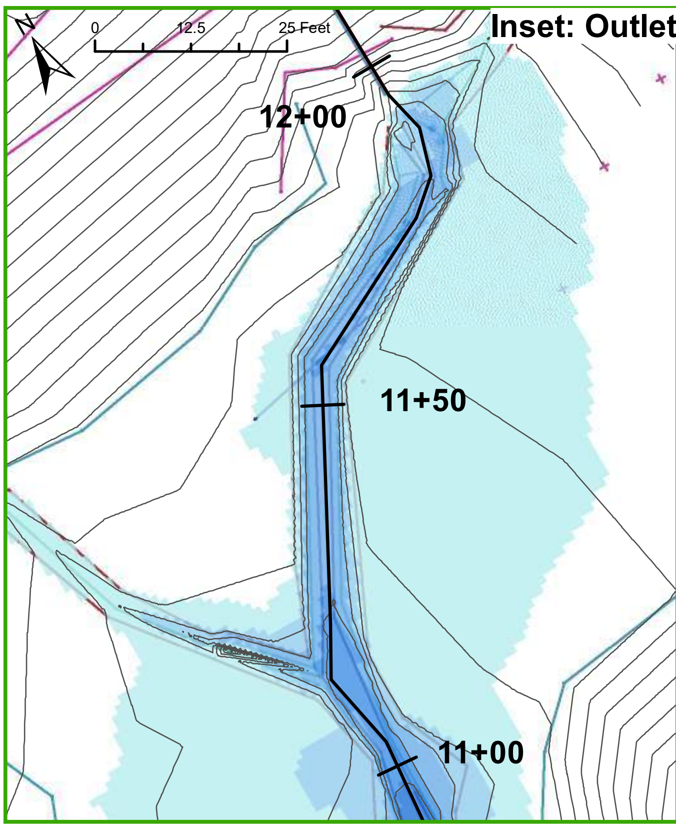
Depth (ft)

- < 1
- 1.0 - 2
- 2.0 - 3
- 3.0 - 4
- 4.0 - 5
- 5.0 - 10
- 10.0 - 15
- > 15.0

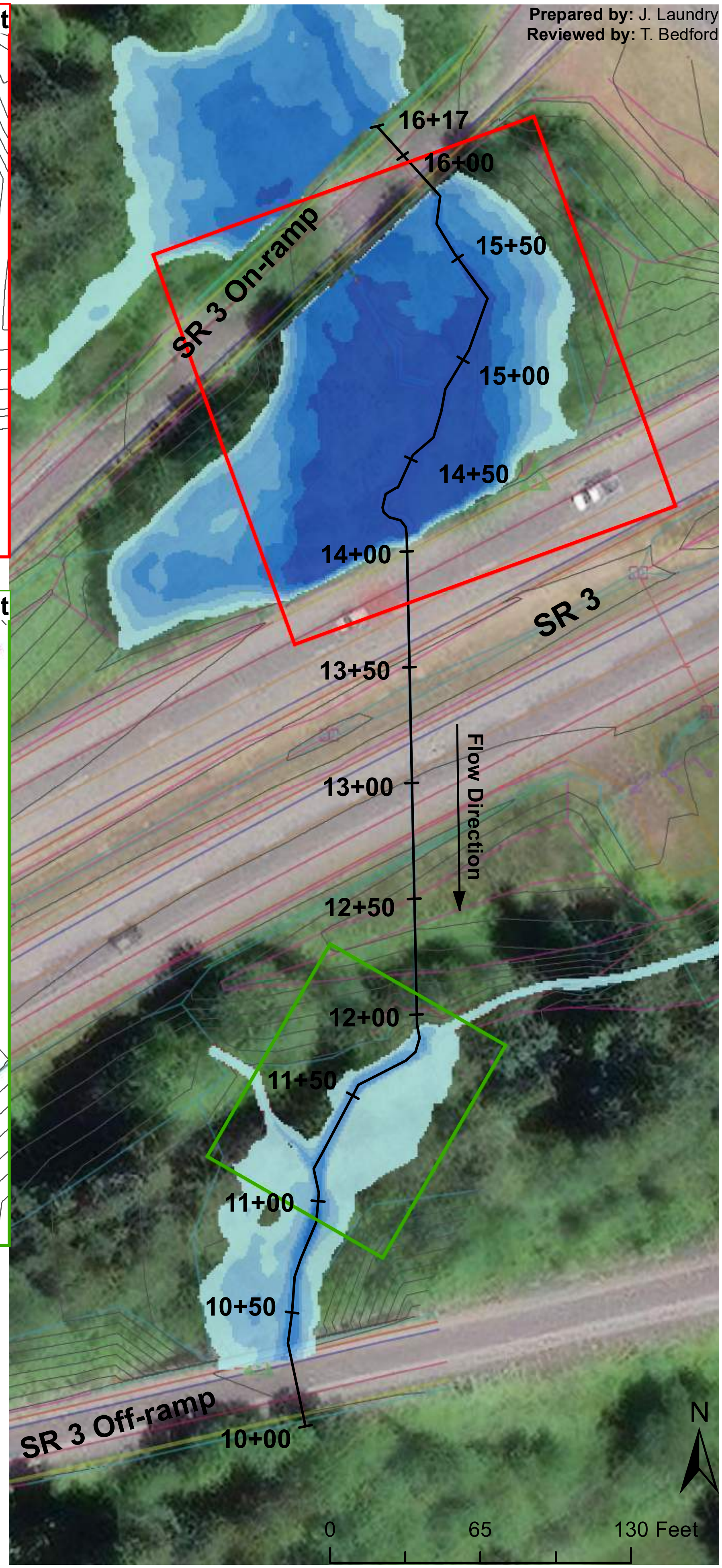
Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs





*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D



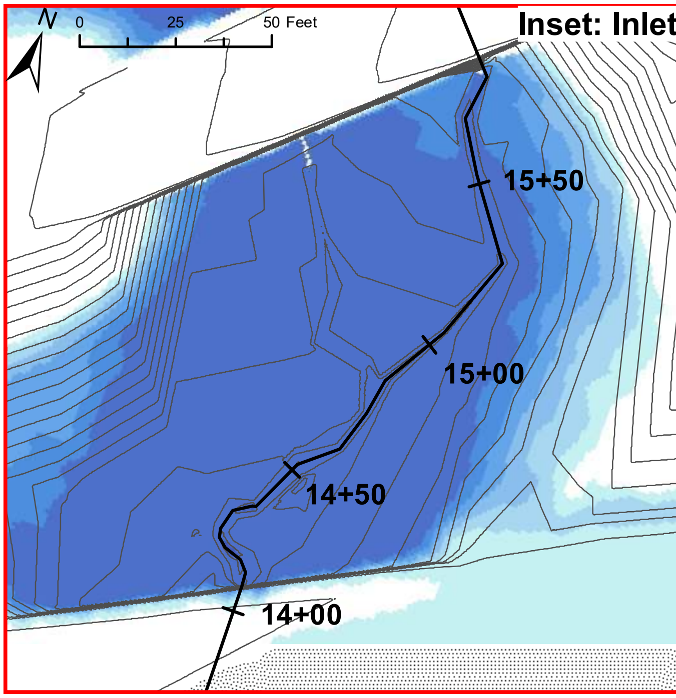
Existing Conditions, 100yr Depth

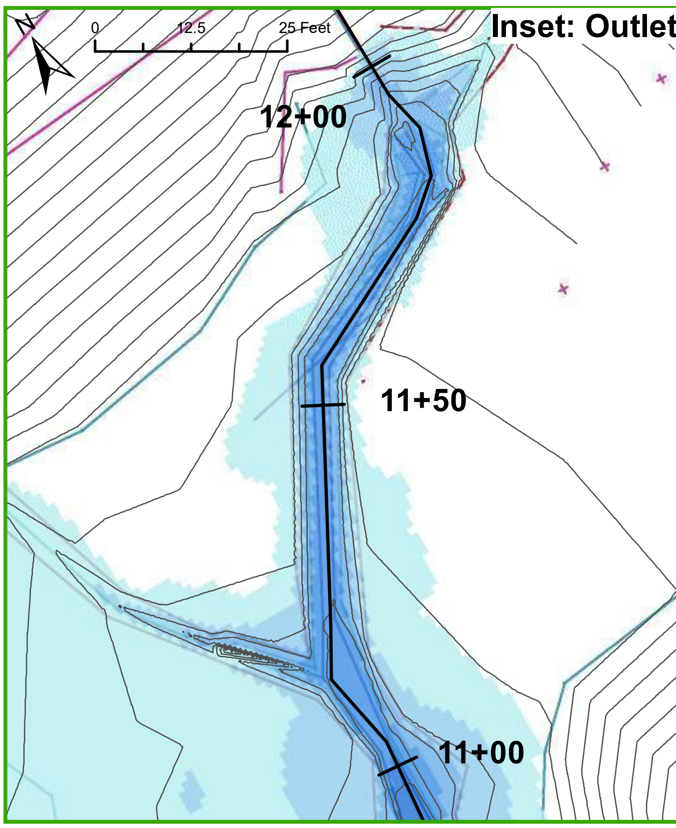
Depth (ft)

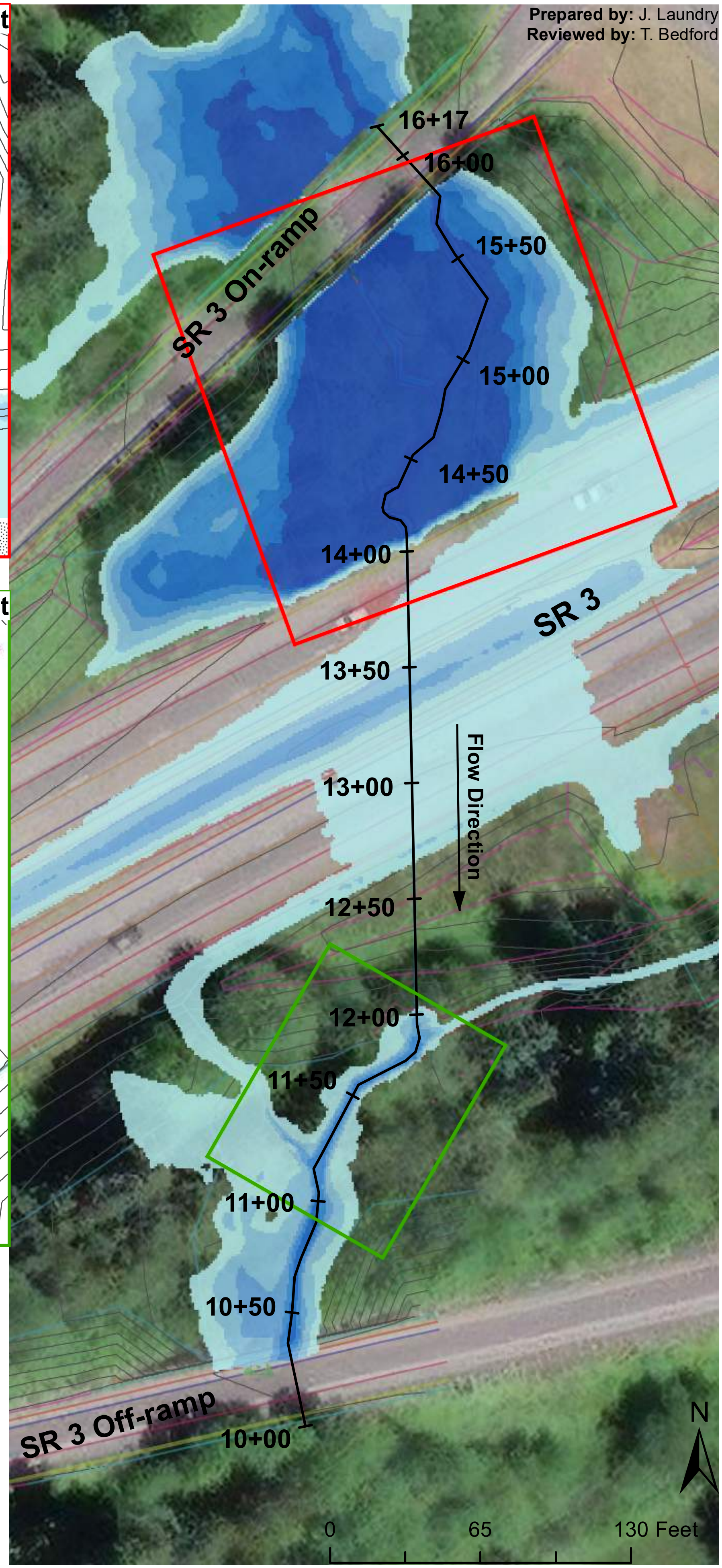
- < 1
- 1.0 - 2
- 2.0 - 3
- 3.0 - 4
- 4.0 - 5
- 5.0 - 10
- 10.0 - 15
- > 15.0

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

Existing Conditions, 500yr Depth

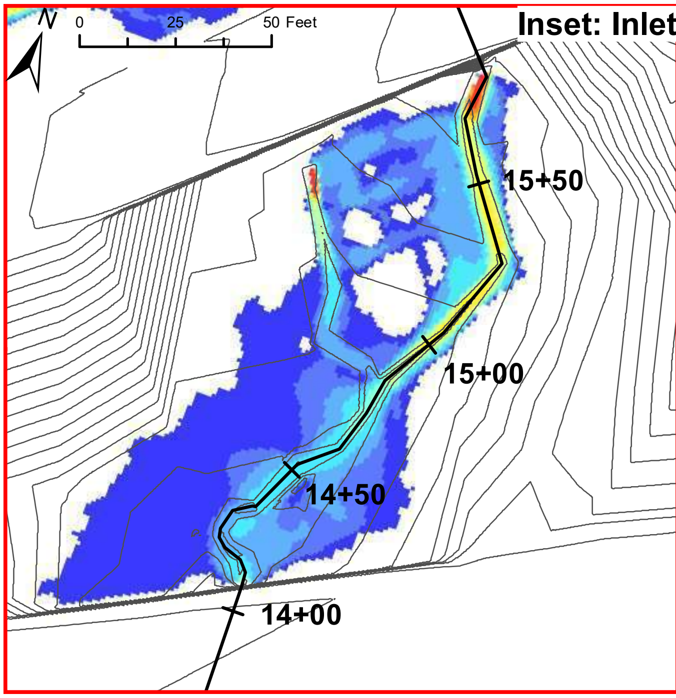
Depth (ft)

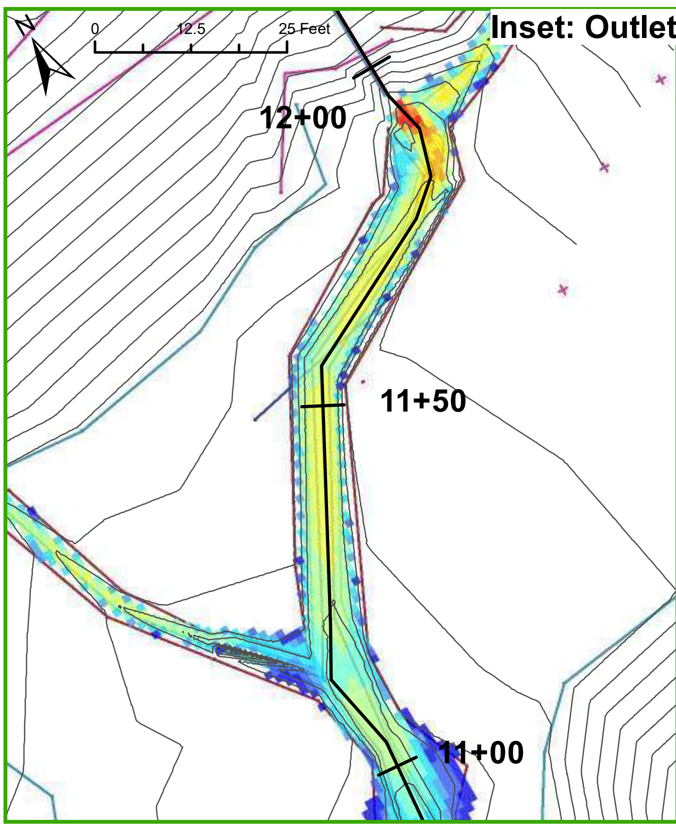
- < 1
- 1.0 - 2
- 2.0 - 3
- 3.0 - 4
- 4.0 - 5
- 5.0 - 10
- 10.0 - 15
- > 15.0

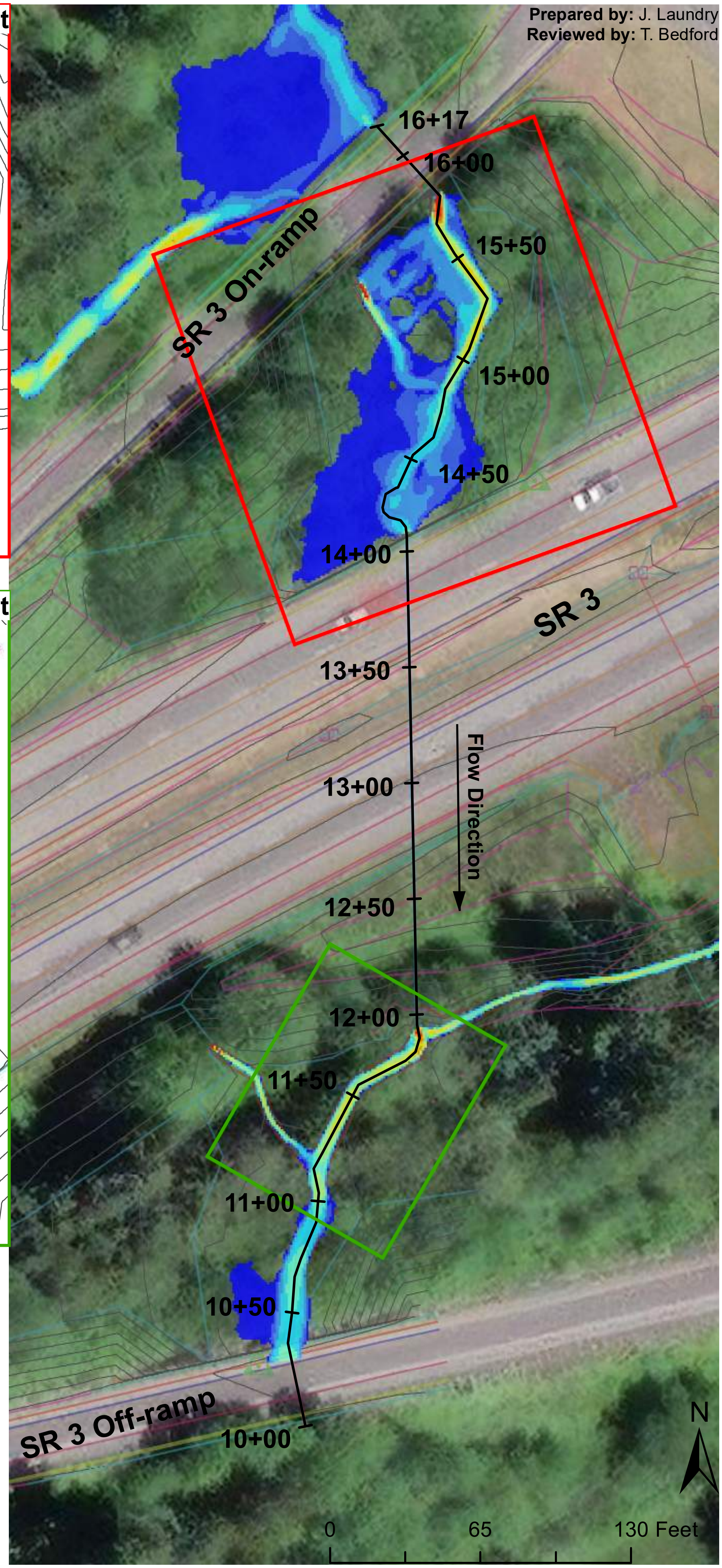
WSDOT OLYMPIC REGION GEC

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

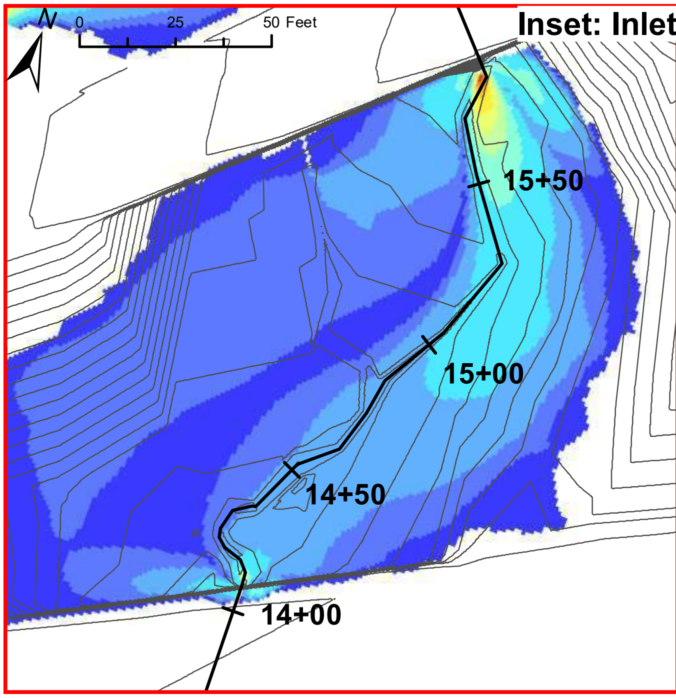
Existing Conditions, 2yr Velocity

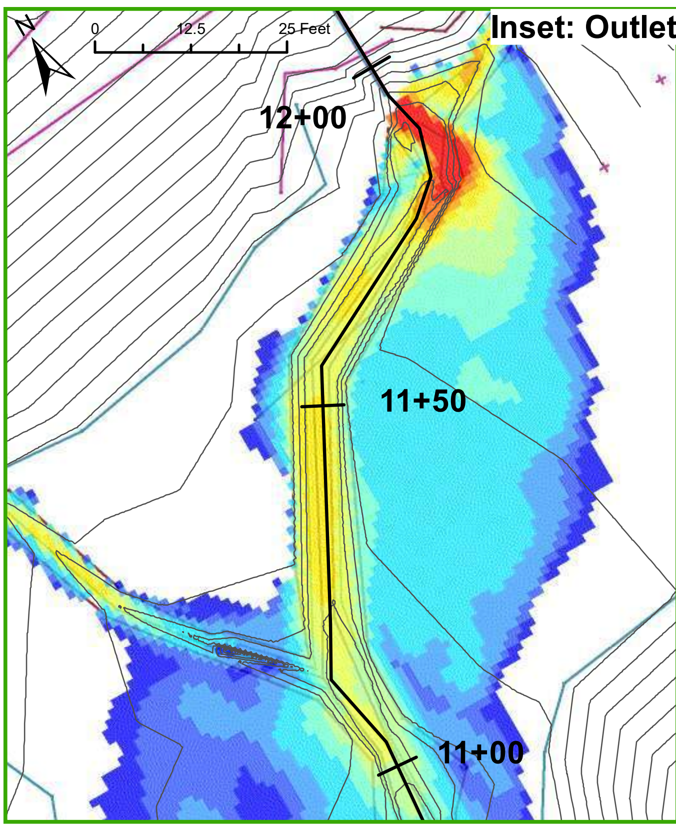
Velocity (fps)

- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 2
- 2.0 - 3
- 3.01 - 4
- 4.0 - 5
- 5.0 - 6
- 6.0 - 7
- 7.0 - 8
- 8.0 - 9

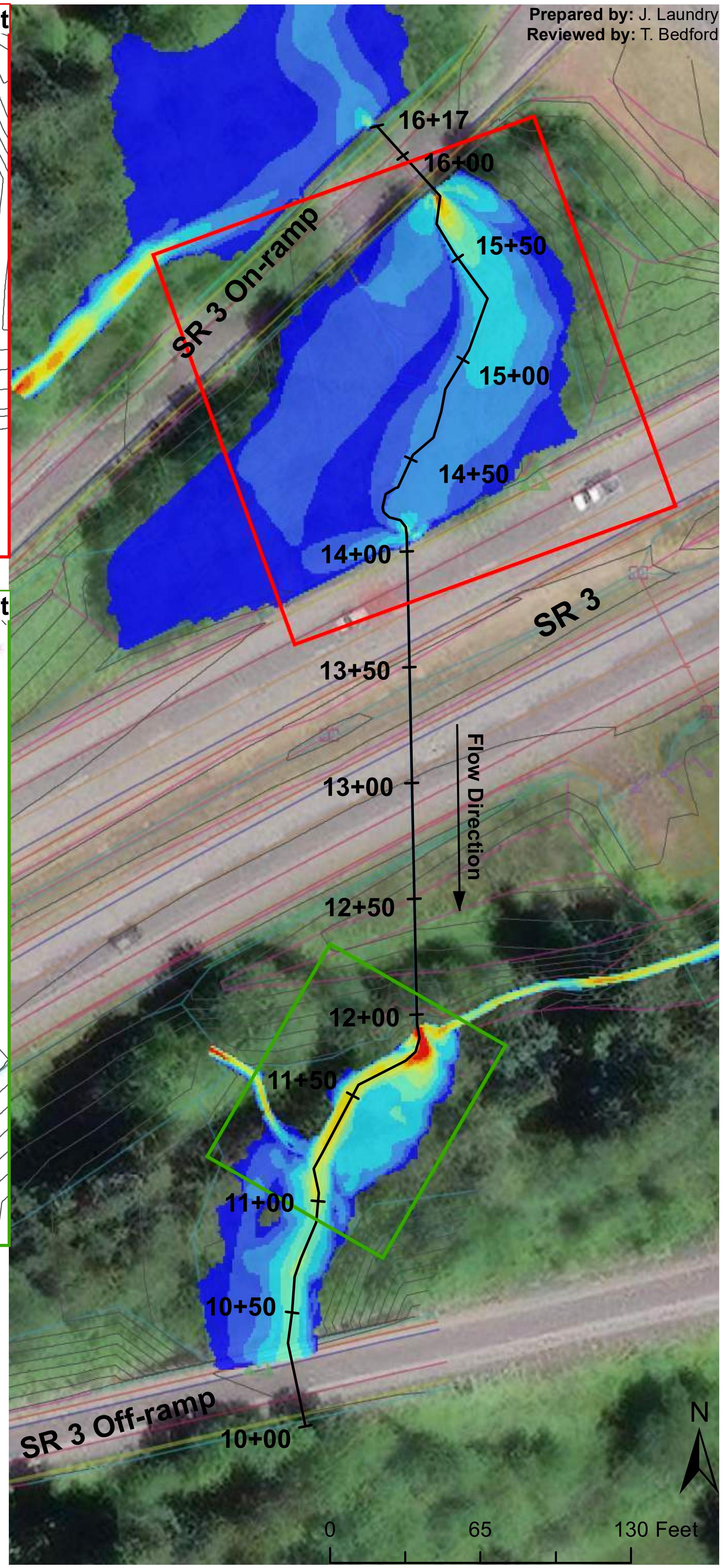
Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs





*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D



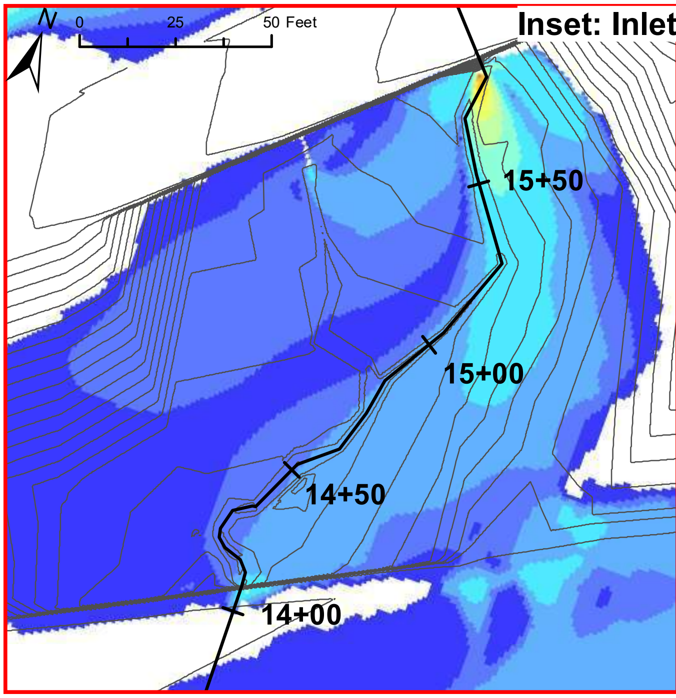
Existing Conditions, 100yr Velocity

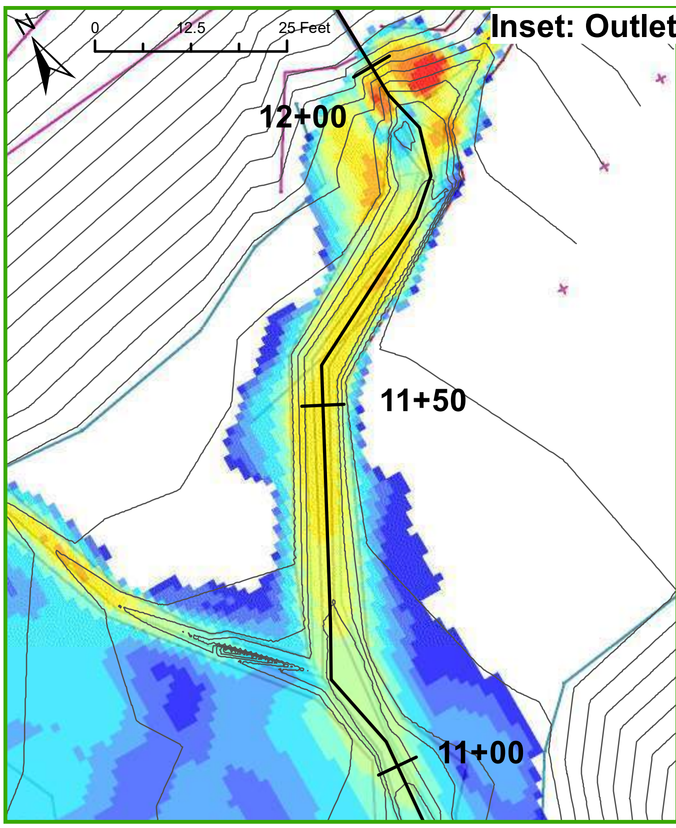
Velocity (fps)

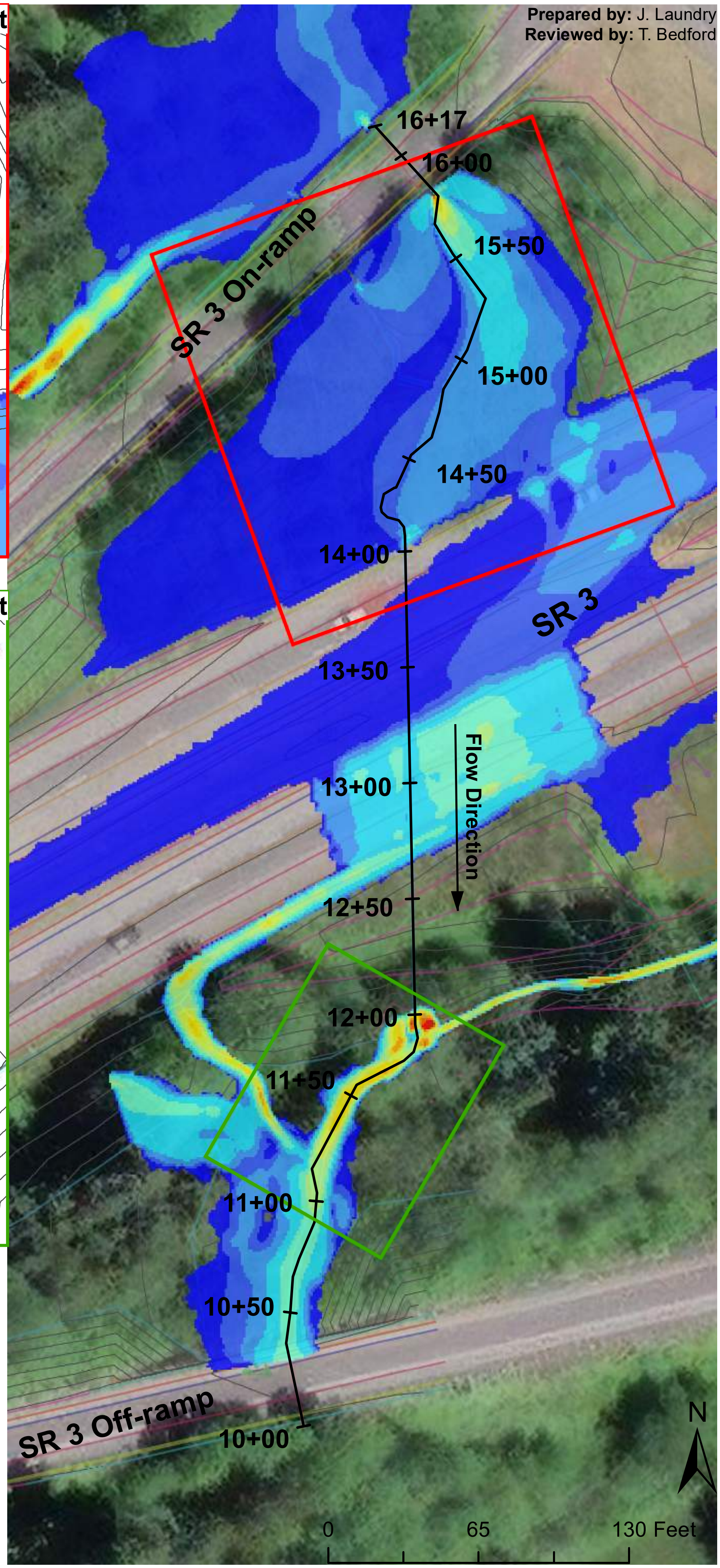
- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 2
- 2.0 - 3
- 3.01 - 4
- 4.0 - 5
- 5.0 - 6
- 6.0 - 7
- 7.0 - 8
- 8.0 - 9

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

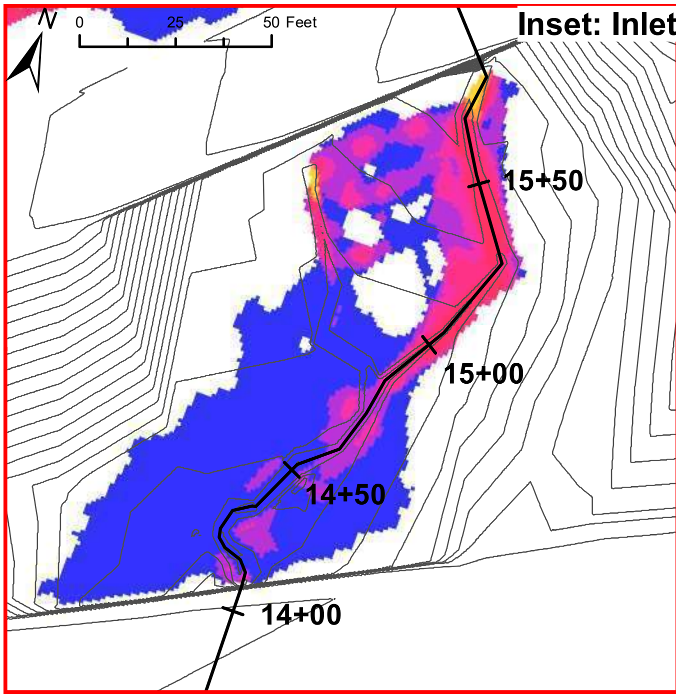
Existing Conditions, 500yr Velocity

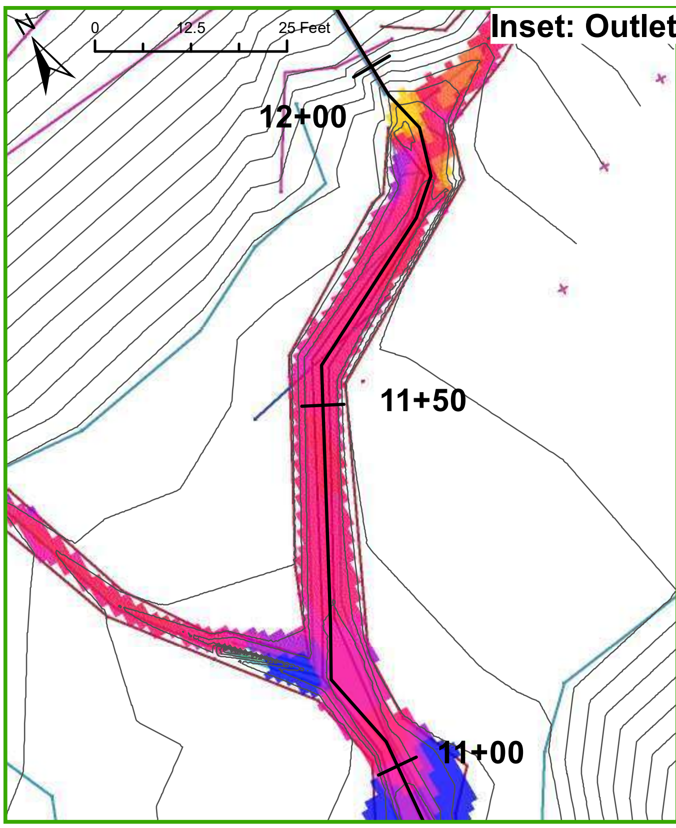
Velocity (fps)

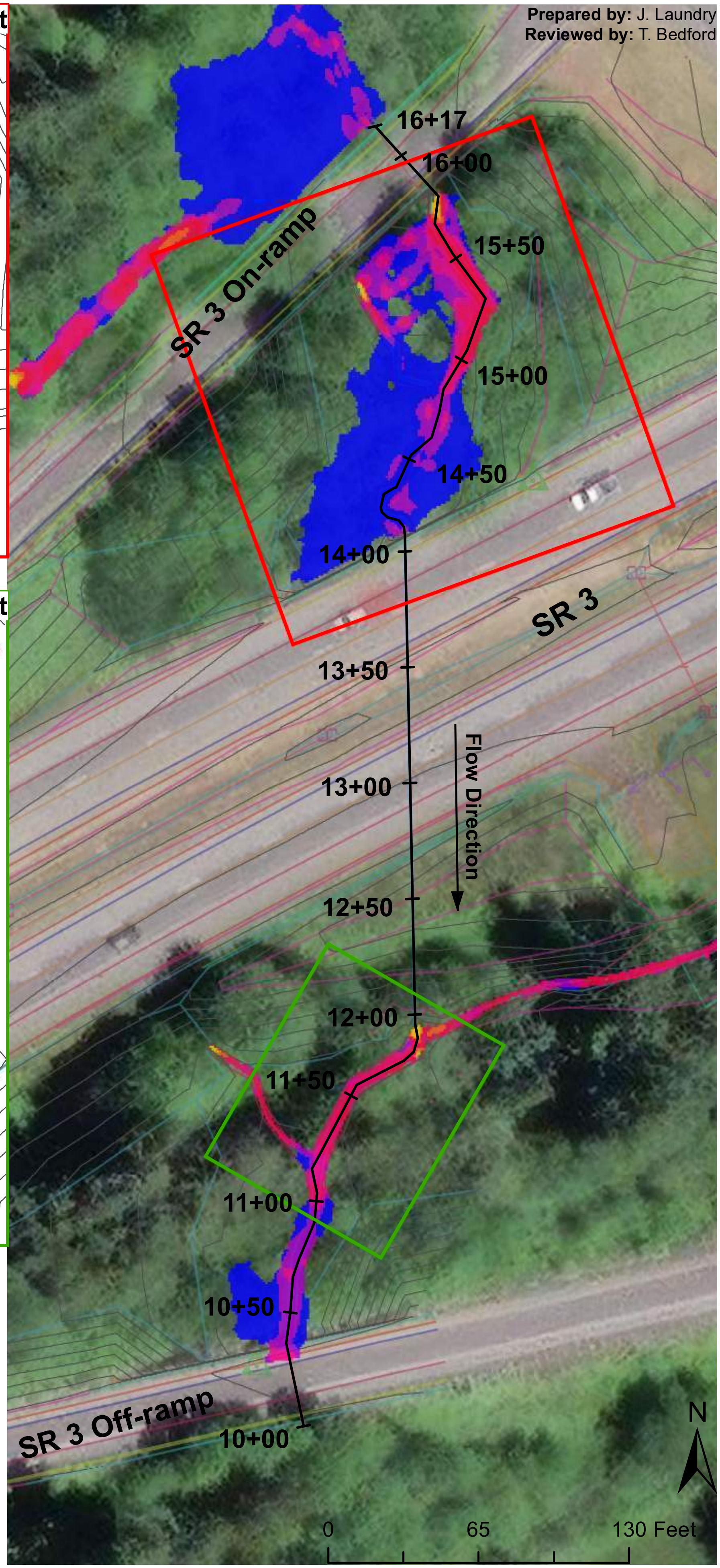
- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 2
- 2.0 - 3
- 3.01 - 4
- 4.0 - 5
- 5.0 - 6
- 6.0 - 7
- 7.0 - 8
- 8.0 - 9

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

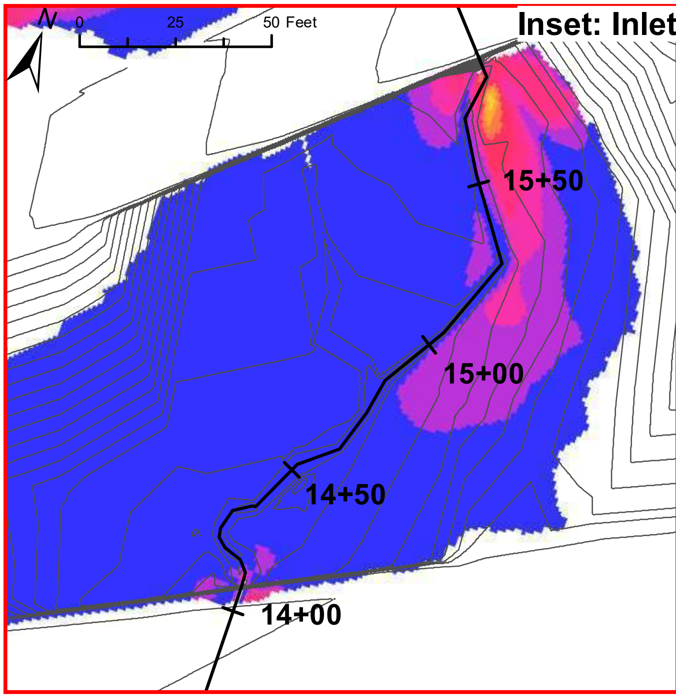
Existing Conditions, 2yr Shear Stress

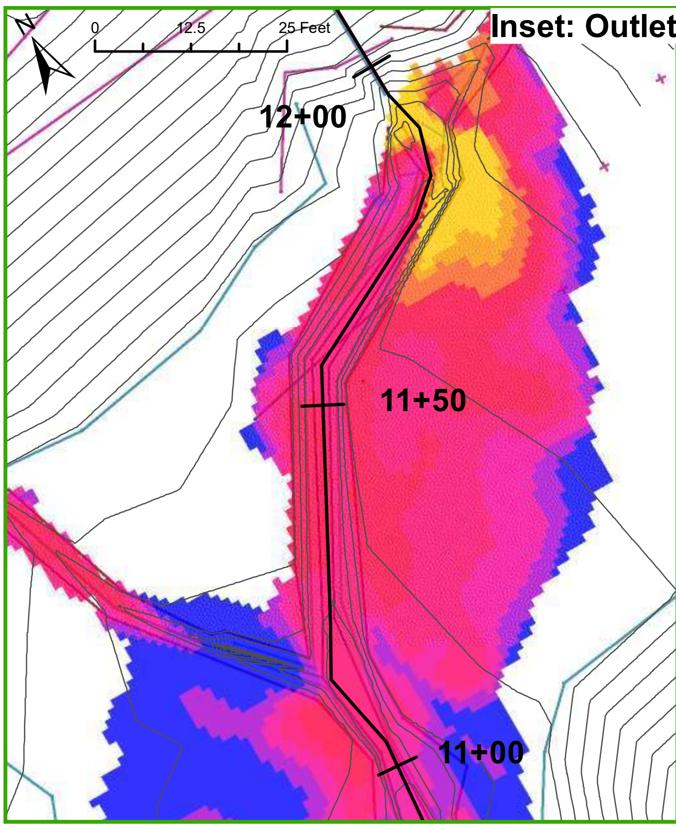
Shear Stress (psf)

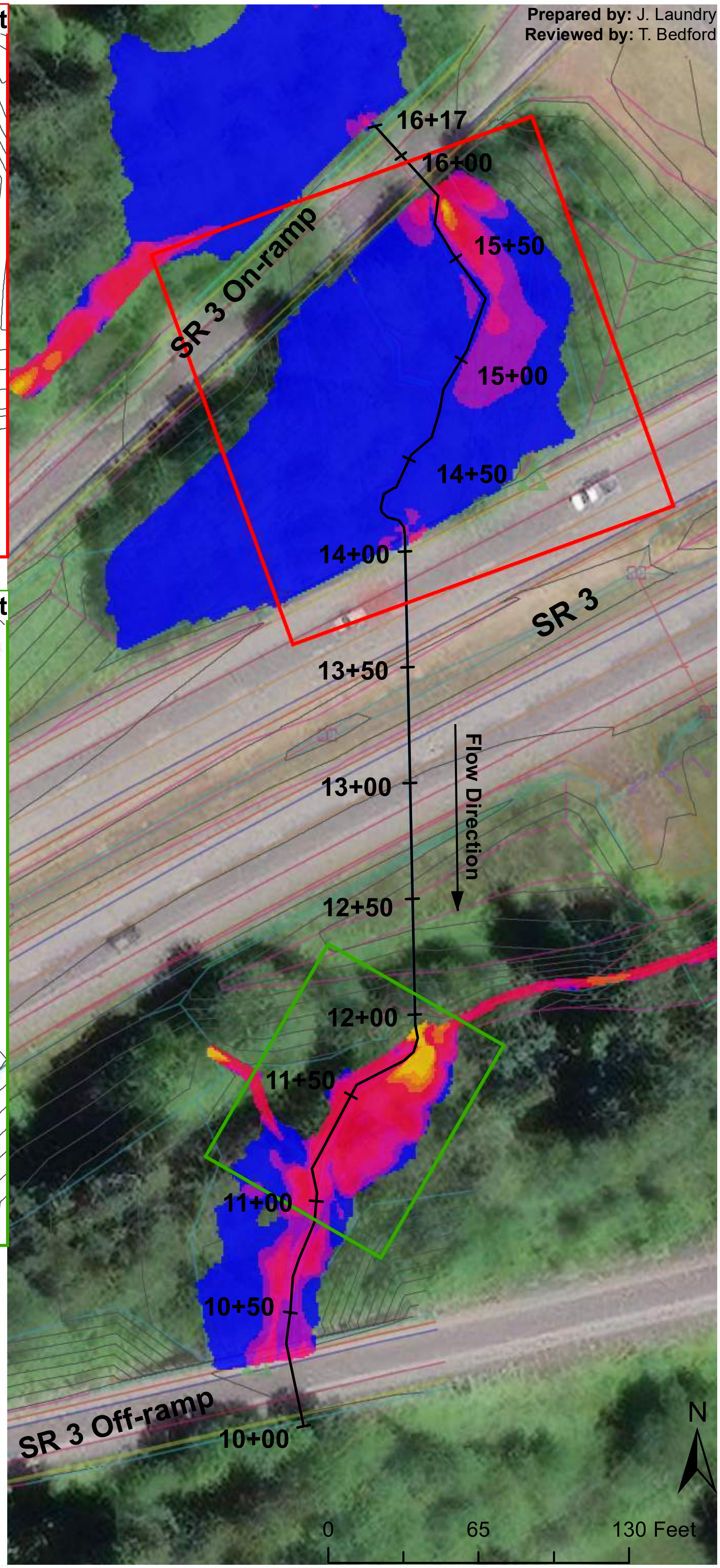
- 0 - 0.1
- 0.10 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- > 4

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

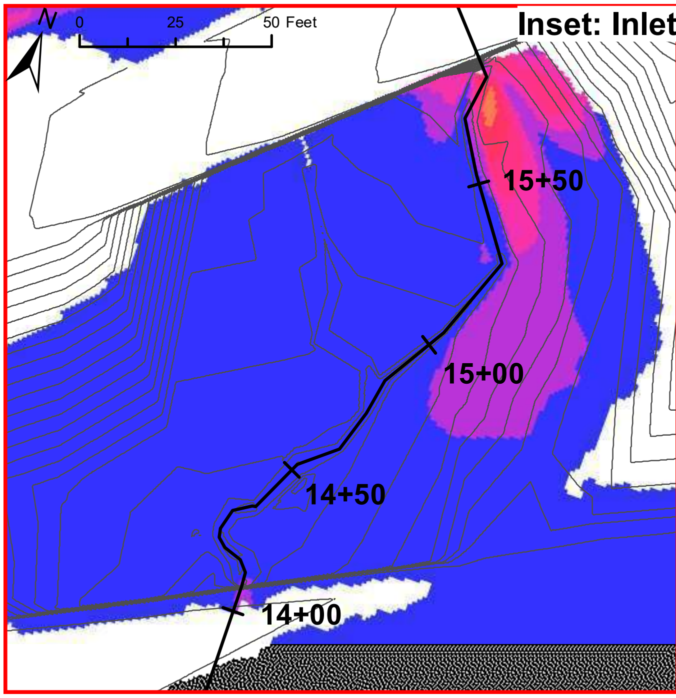
Existing Conditions,100yr Shear Stress

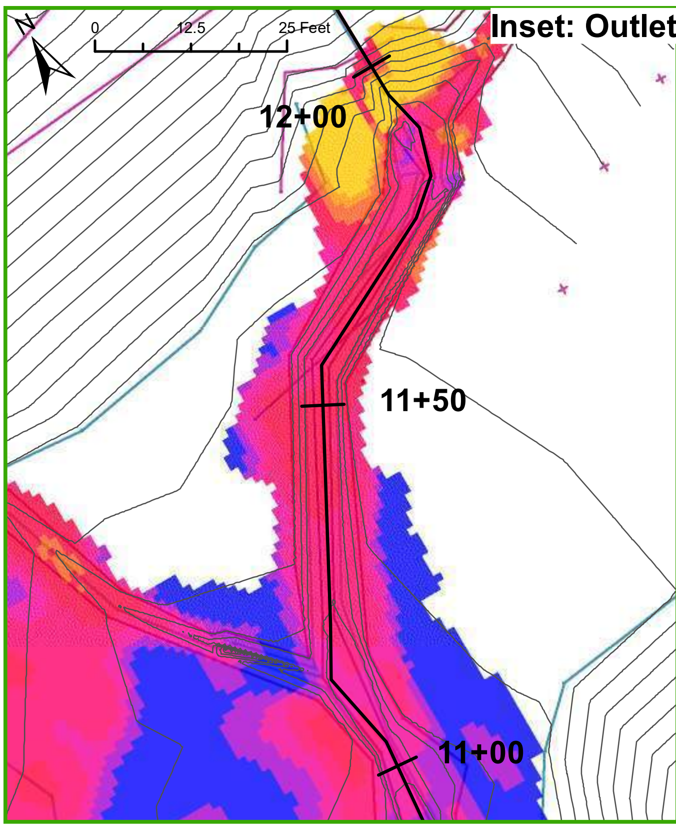
Shear Stress (psf)

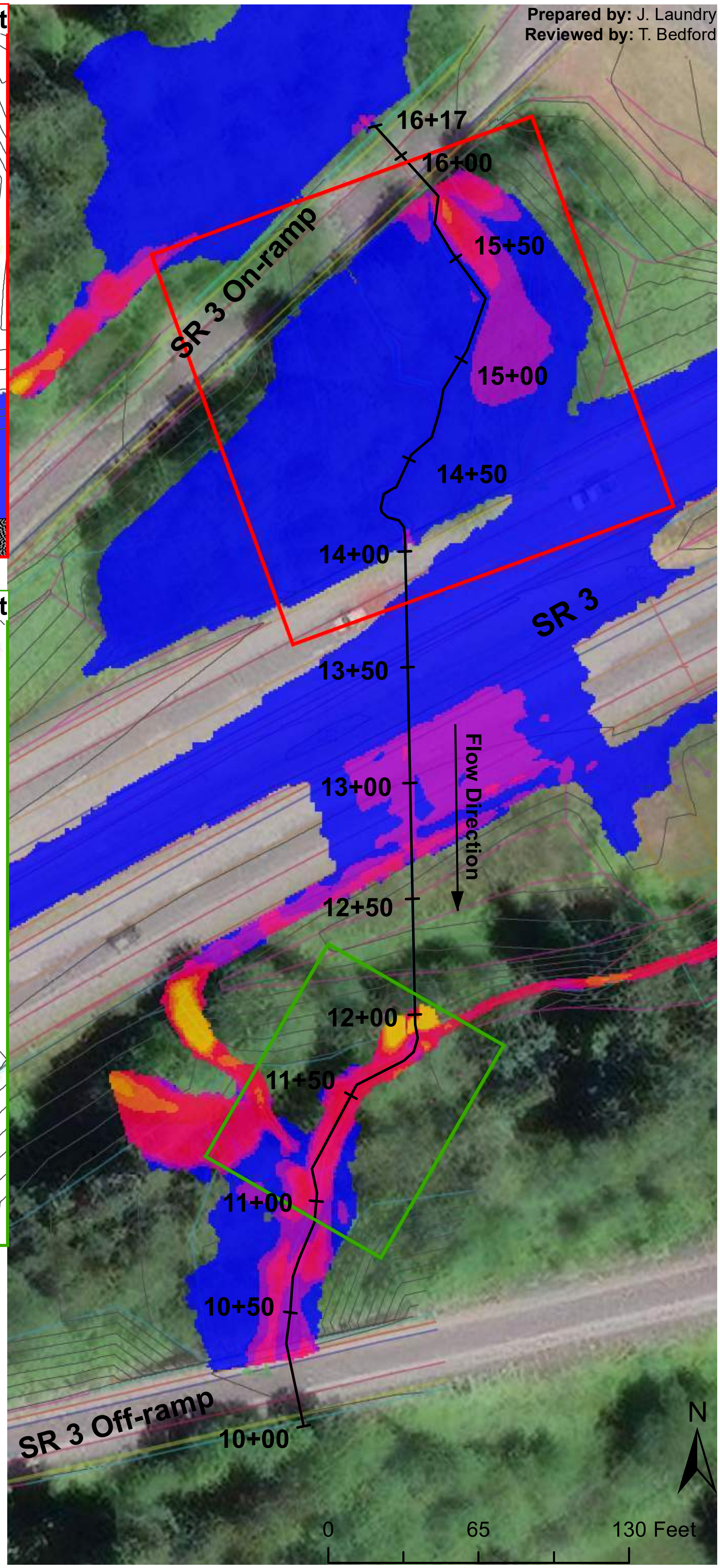
0 - 0.1	0.5 - 1	3 - 4
0.10 - 0.25	1 - 2	> 4
0.25 - 0.5	2 - 3	

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







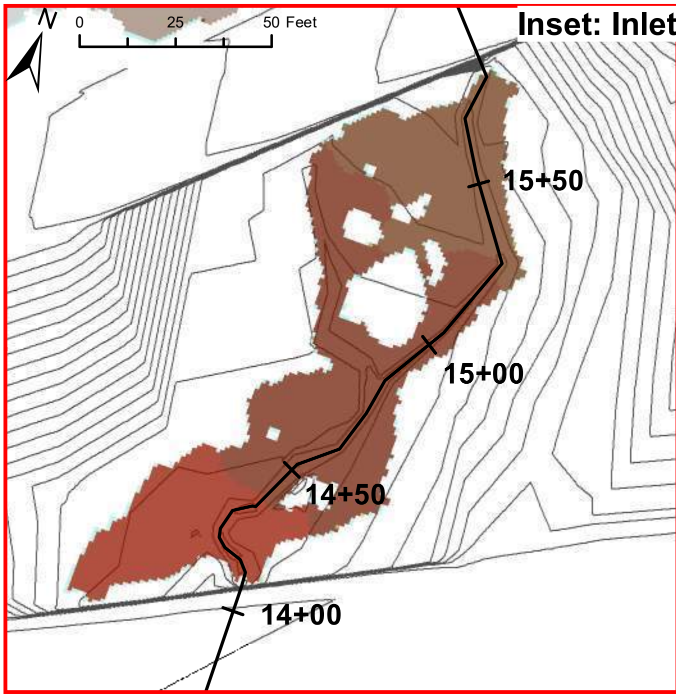
*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

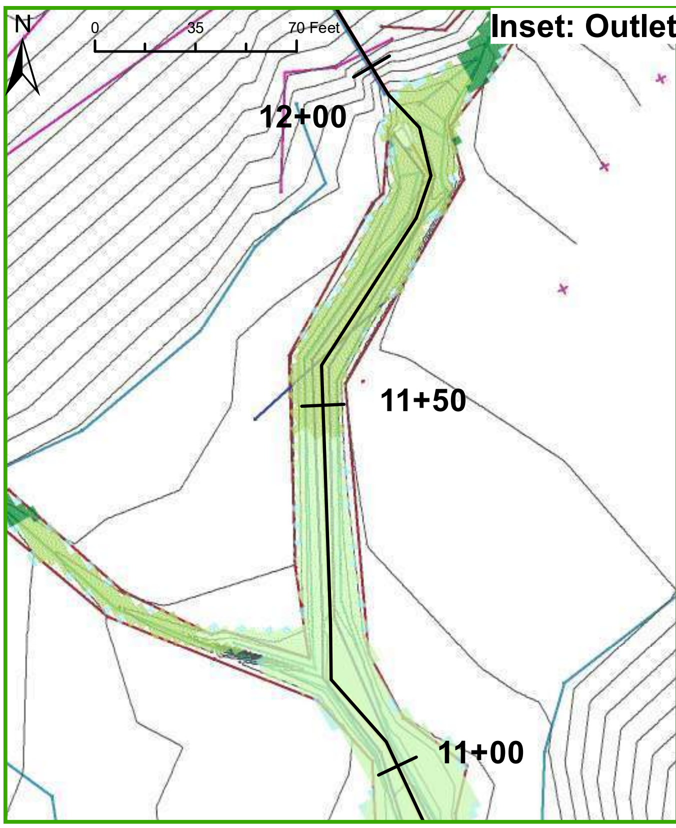
Existing Conditions, 500yr Shear Stress

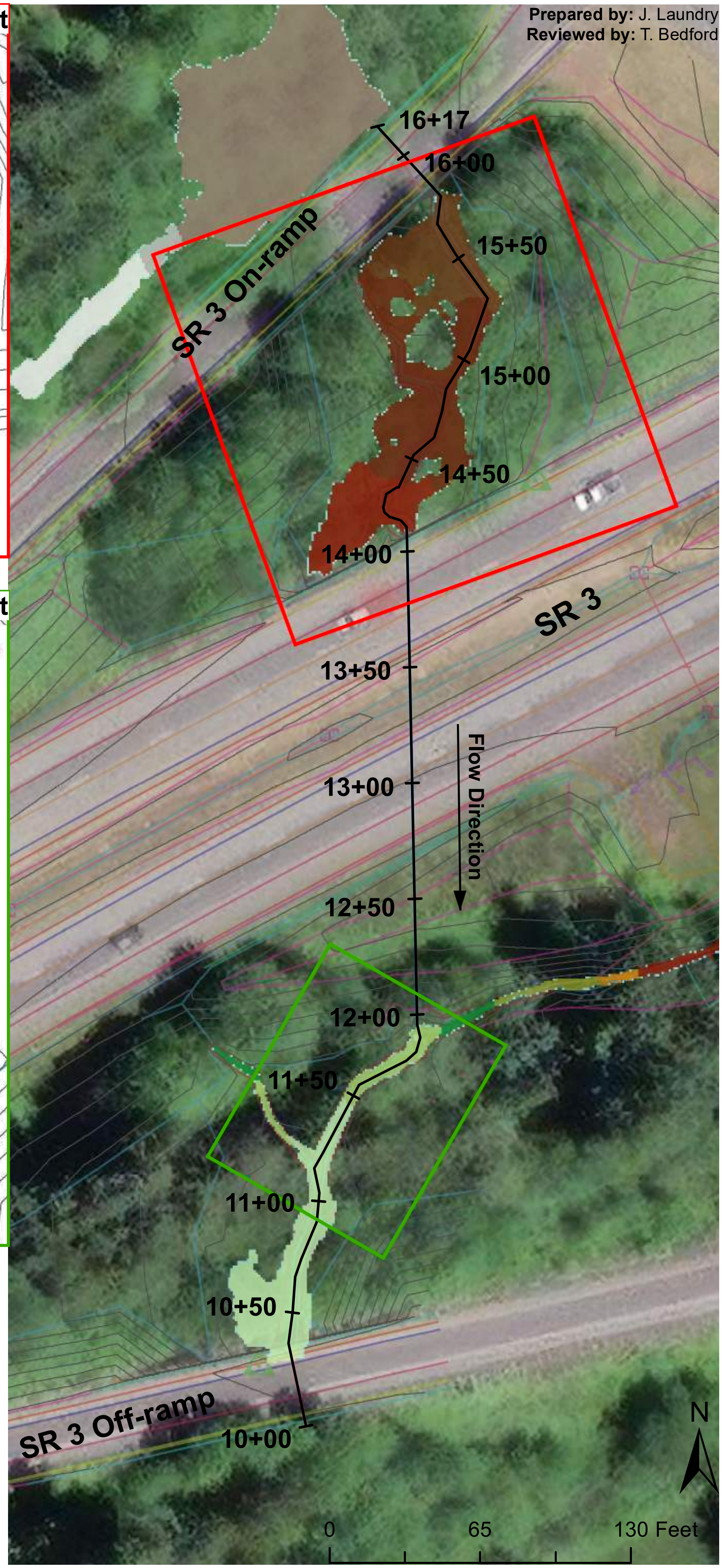
Shear Stress (psf)

- 0 - 0.1
- 0.10 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- > 4

Appendix H
SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

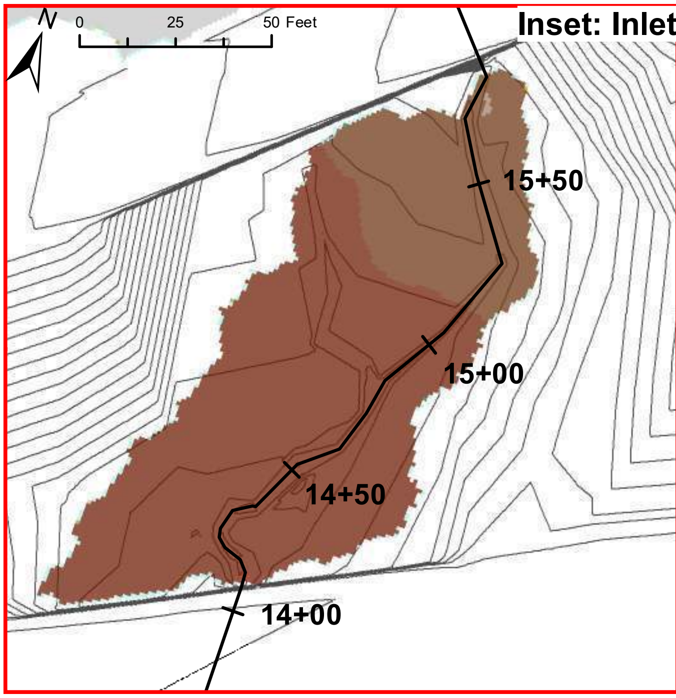
Natural Conditions, 2yr Water Surface Elevation

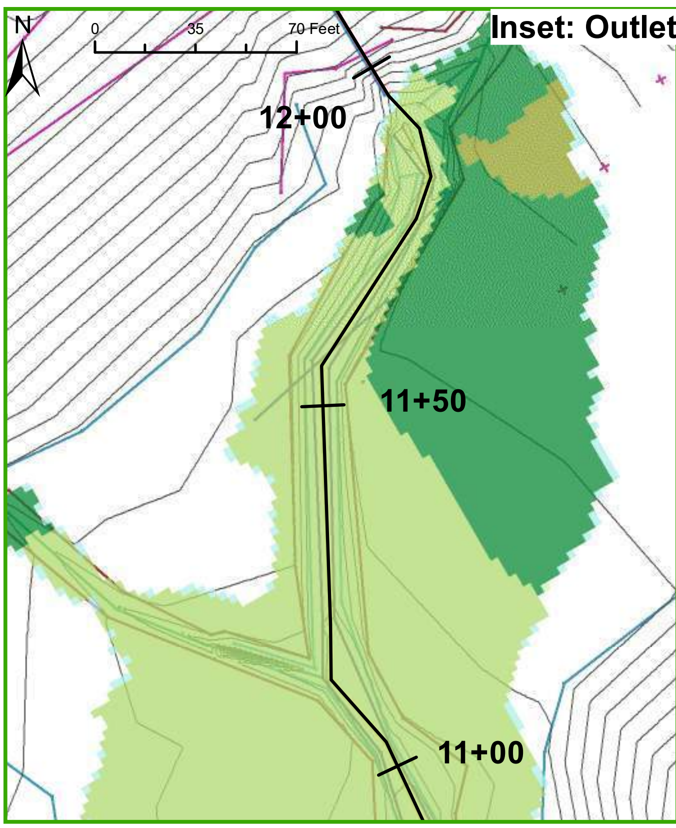
Water Surface Elevation (ft, NAVD '88)

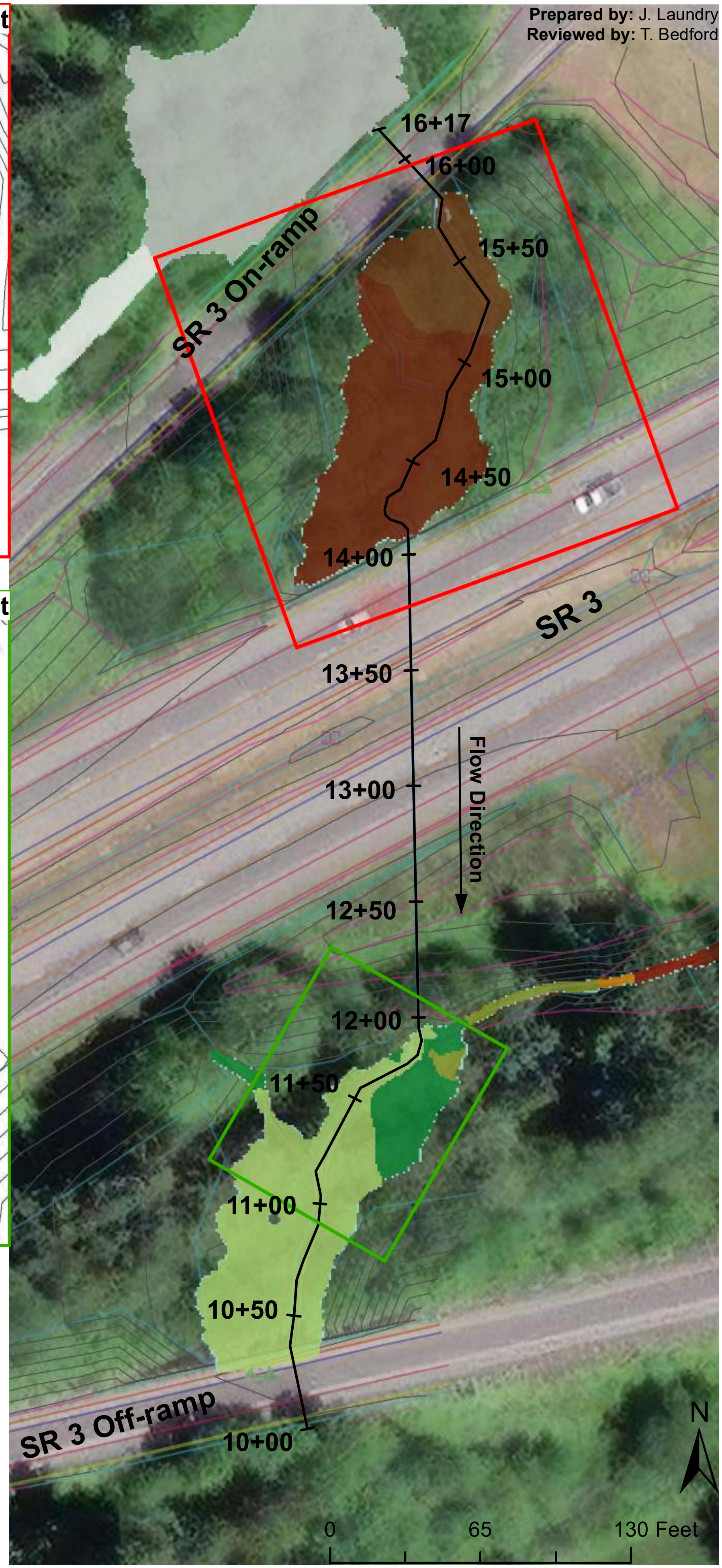
- < 221
- 221.0 - 223
- 223.0 - 225
- 225.0 - 227
- 227.0 - 229
- 229.0 - 231
- 231.0 - 233
- 233.0 - 235
- 235.0 - 237
- 237.0 - 239
- 239.0 - 241
- > 241

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

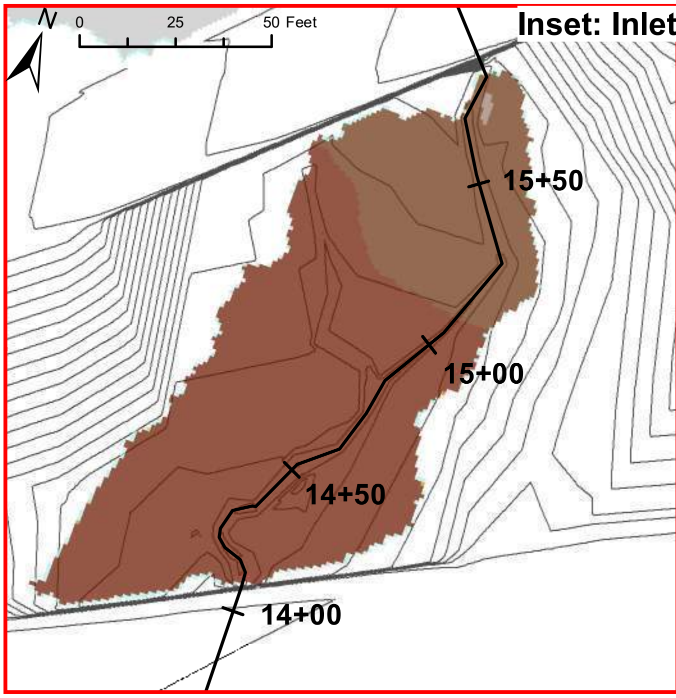
Natural Conditions, 100yr Water Surface Elevation

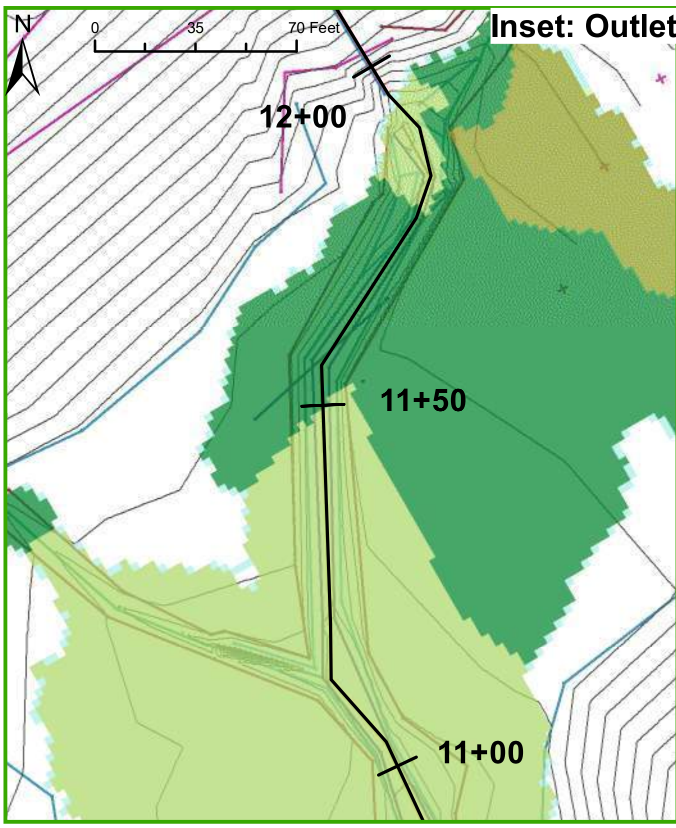
Water Surface Elevation (ft, NAVD '88)

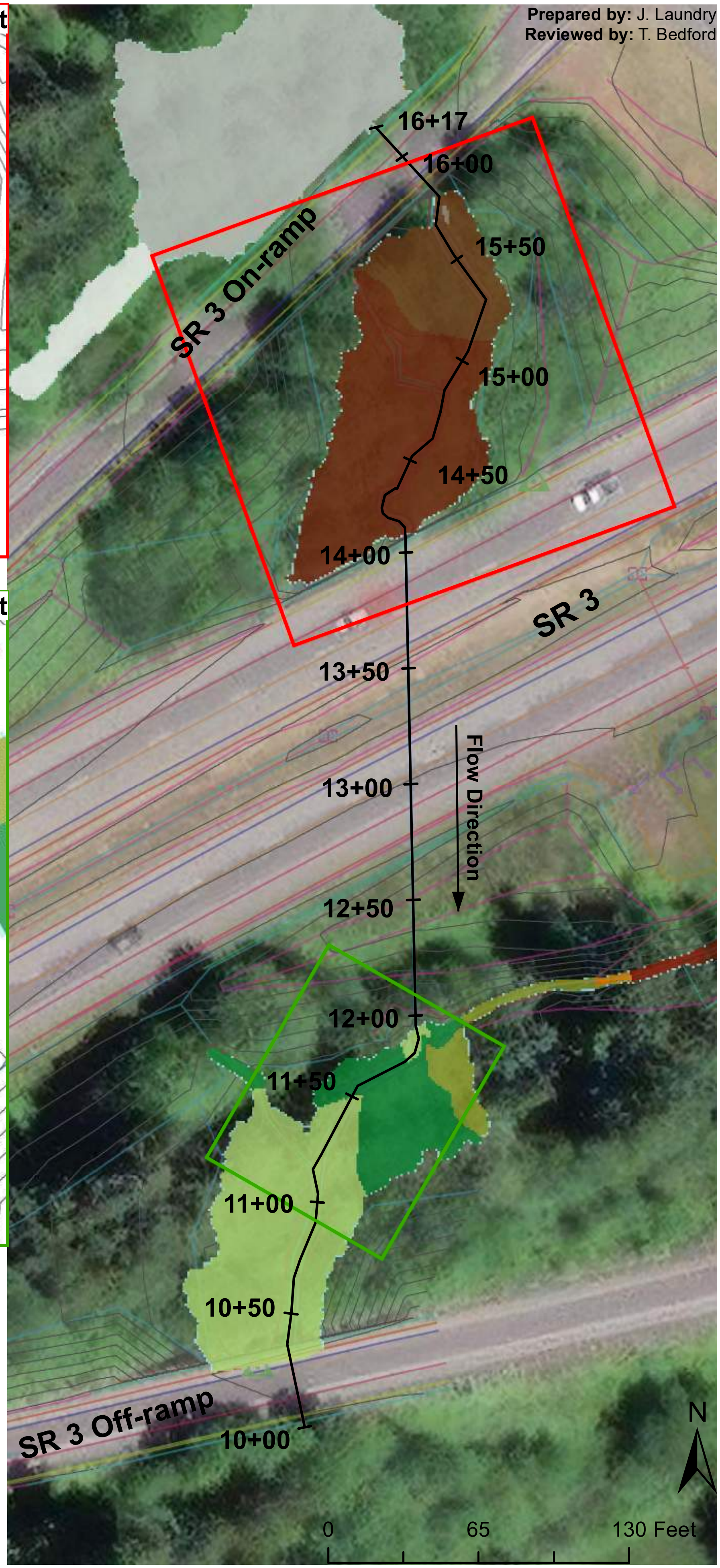
< 221	225.0 - 227	231.0 - 233	237.0 - 239
221.0 - 223	227.0 - 229	233.0 - 235	239.0 - 241
223.0 - 225	229.0 - 231	235.0 - 237	> 241

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

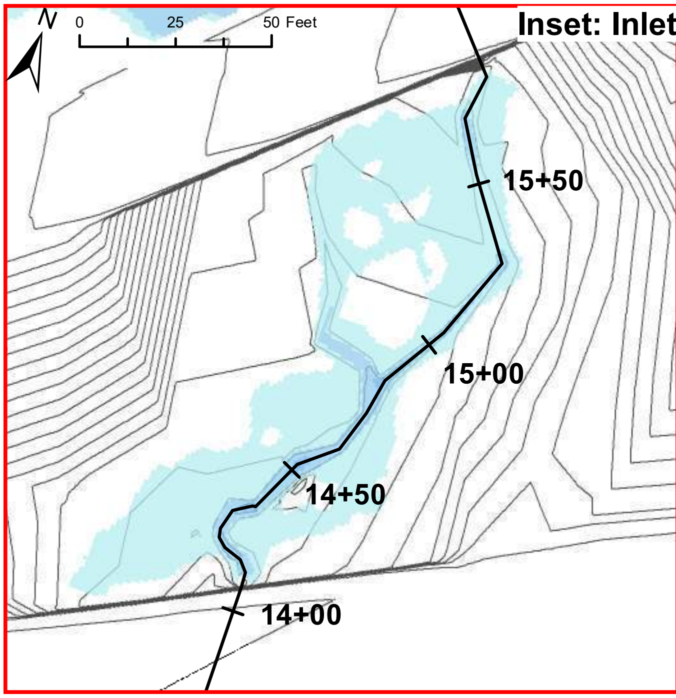
Natural Conditions, 500yr Water Surface Elevation

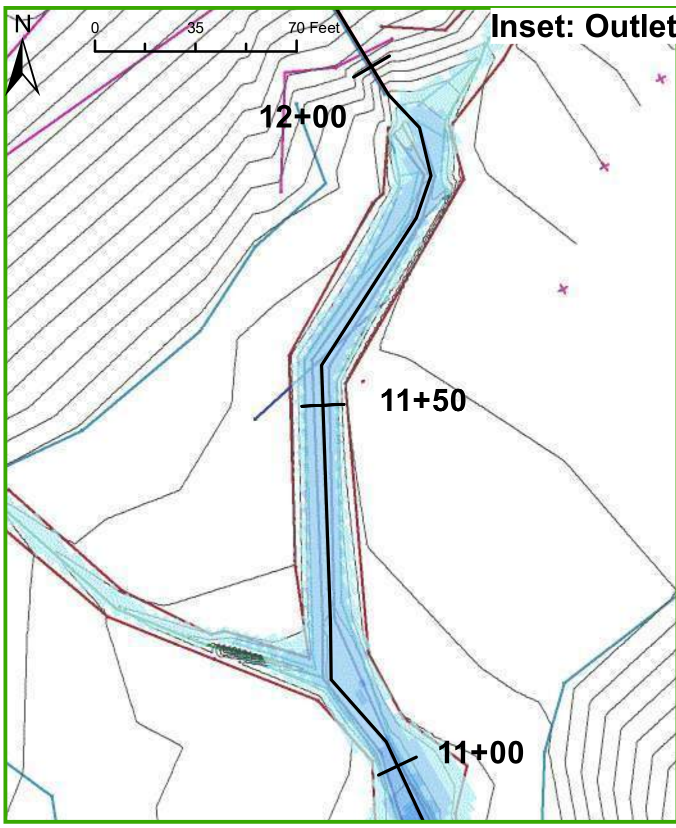
Water Surface Elevation (ft, NAVD '88)

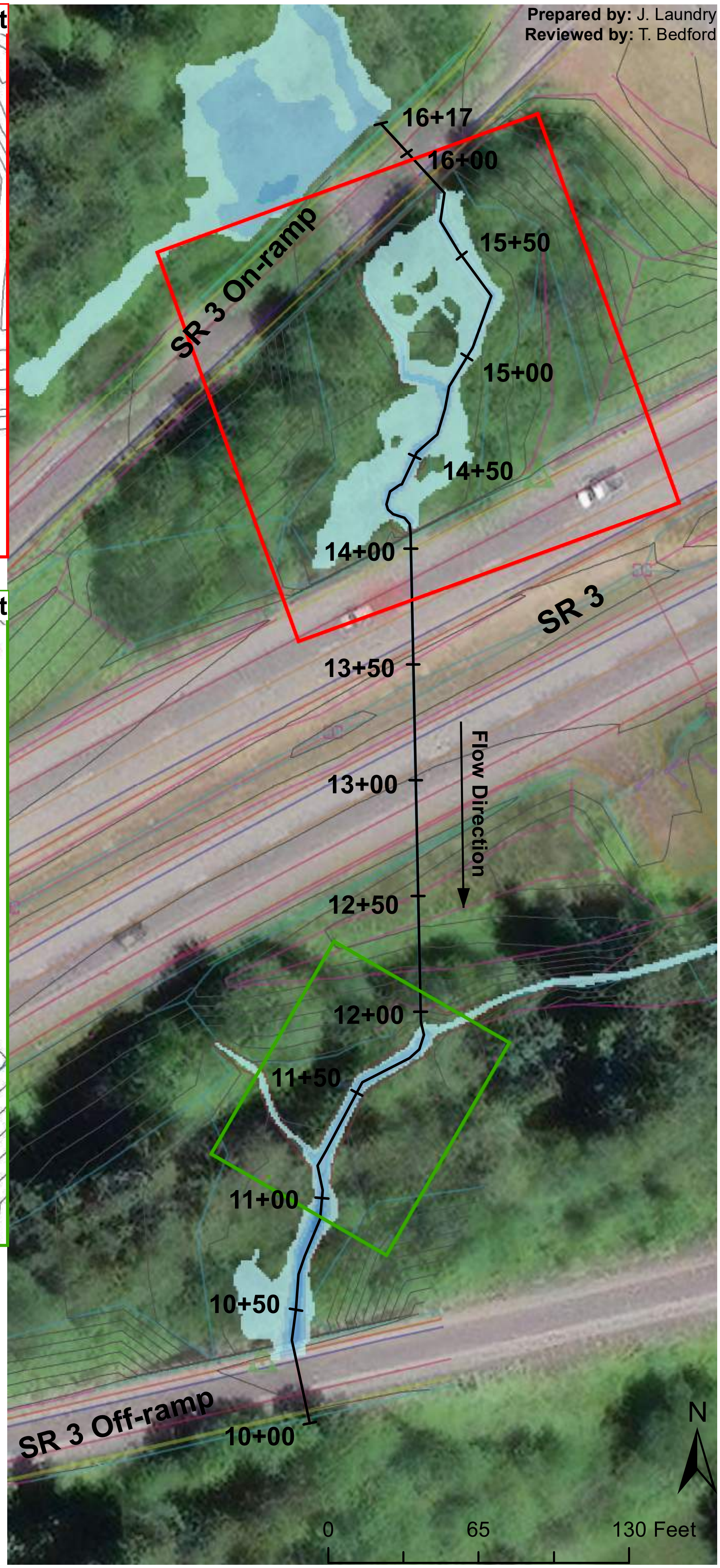
- < 221
- 221.0 - 223
- 223.0 - 225
- 225.0 - 227
- 227.0 - 229
- 229.0 - 231
- 231.0 - 233
- 233.0 - 235
- 235.0 - 237
- 237.0 - 239
- 239.0 - 241
- > 241

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

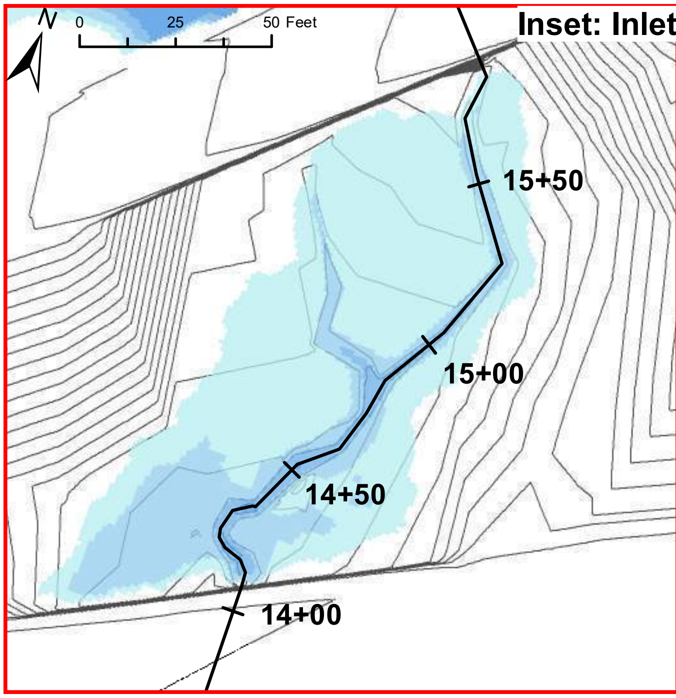
Natural Conditions, 2yr Depth

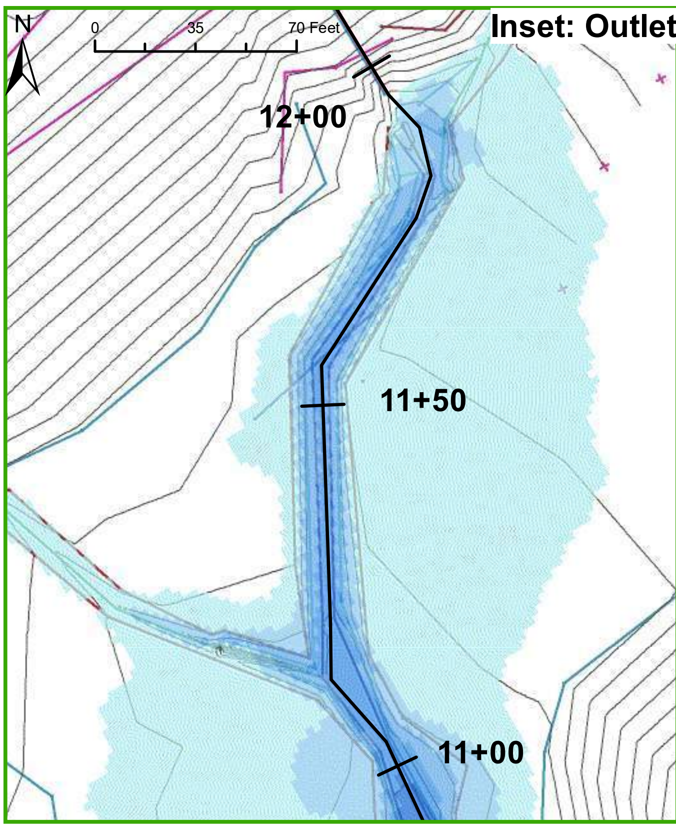
Depth (ft)

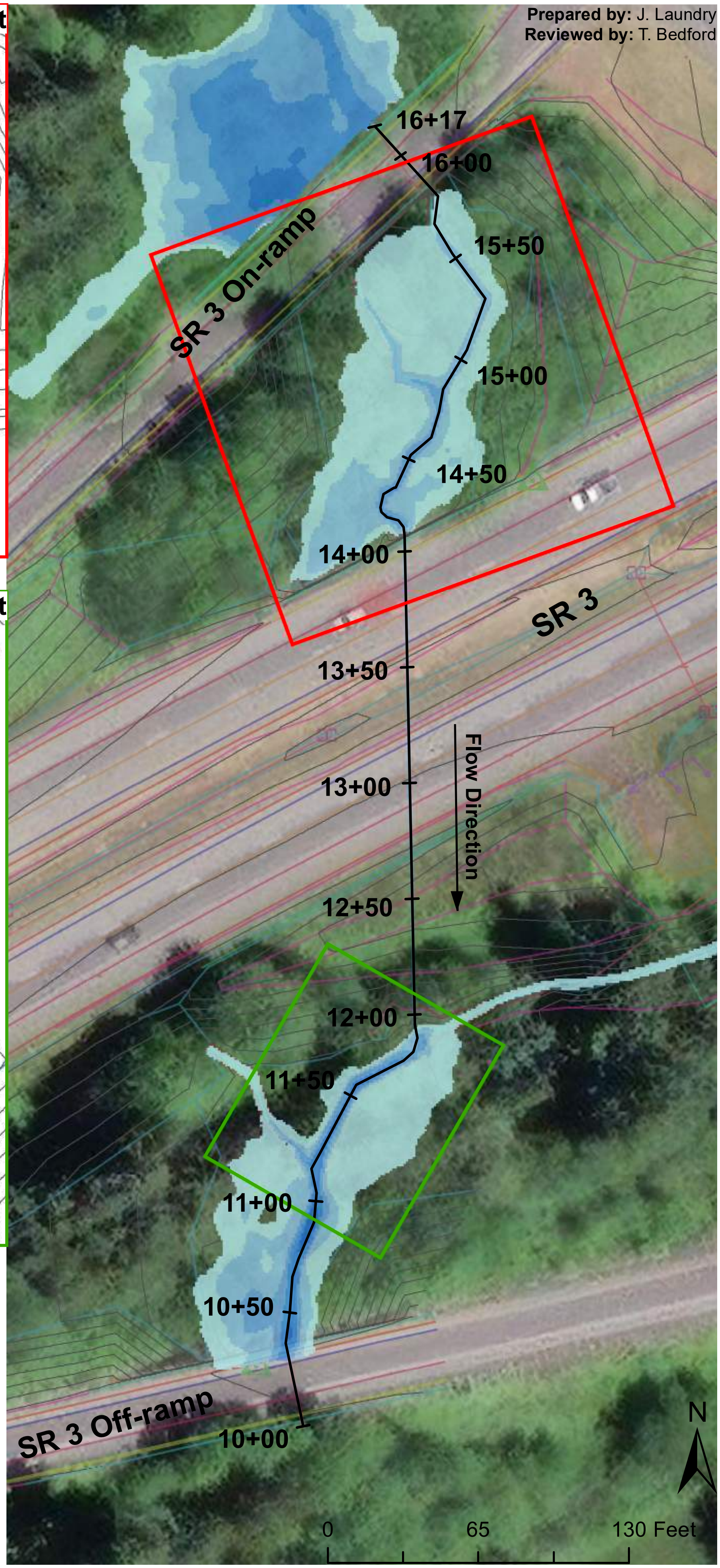
- < 1
- 1.0 - 2
- 2.0 - 3
- 3.0 - 4
- 4.0 - 5
- 5.0 - 10
- 10.0 - 15
- > 15.0

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs





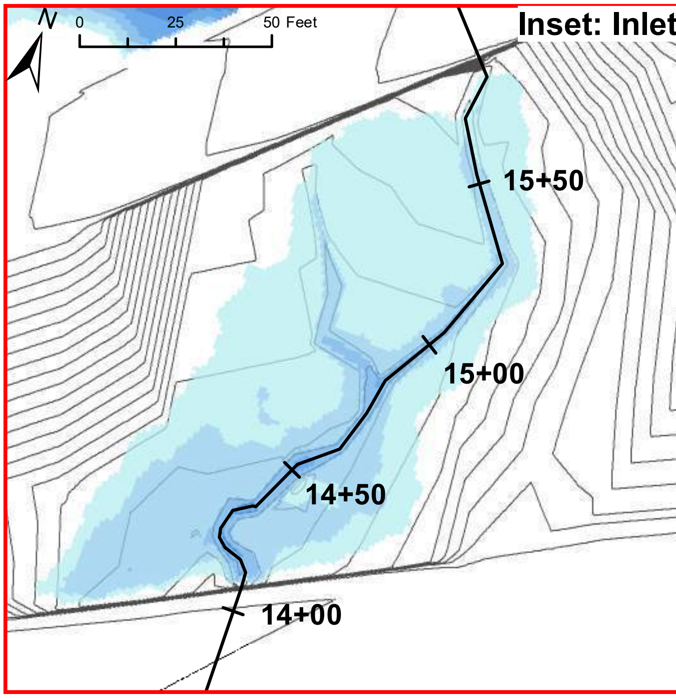


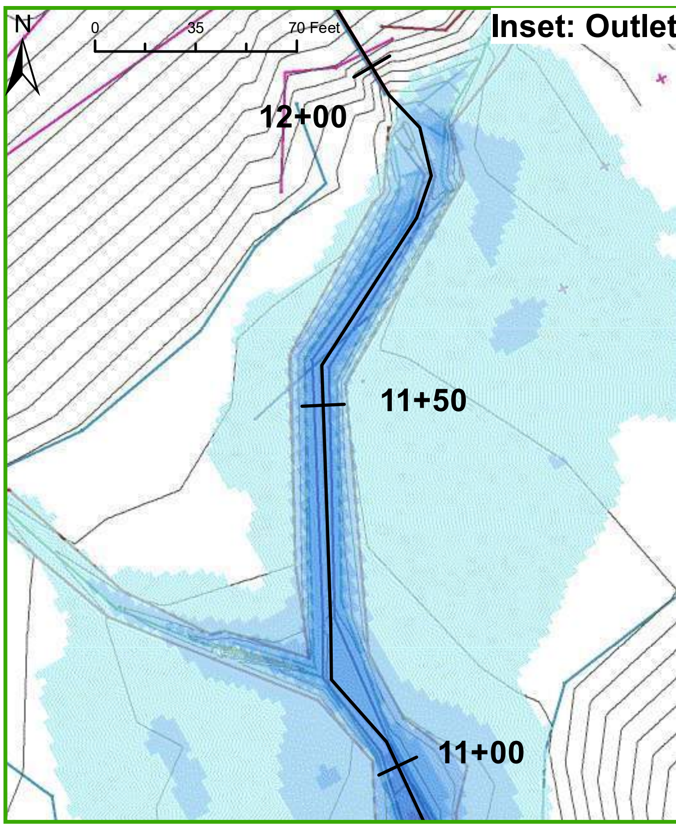
*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

Natural Conditions, 100yr Depth

Depth (ft)

- < 1
- 1.0 - 2
- 2.0 - 3
- 3.0 - 4
- 4.0 - 5
- 5.0 - 10
- 10.0 - 15
- > 15.0





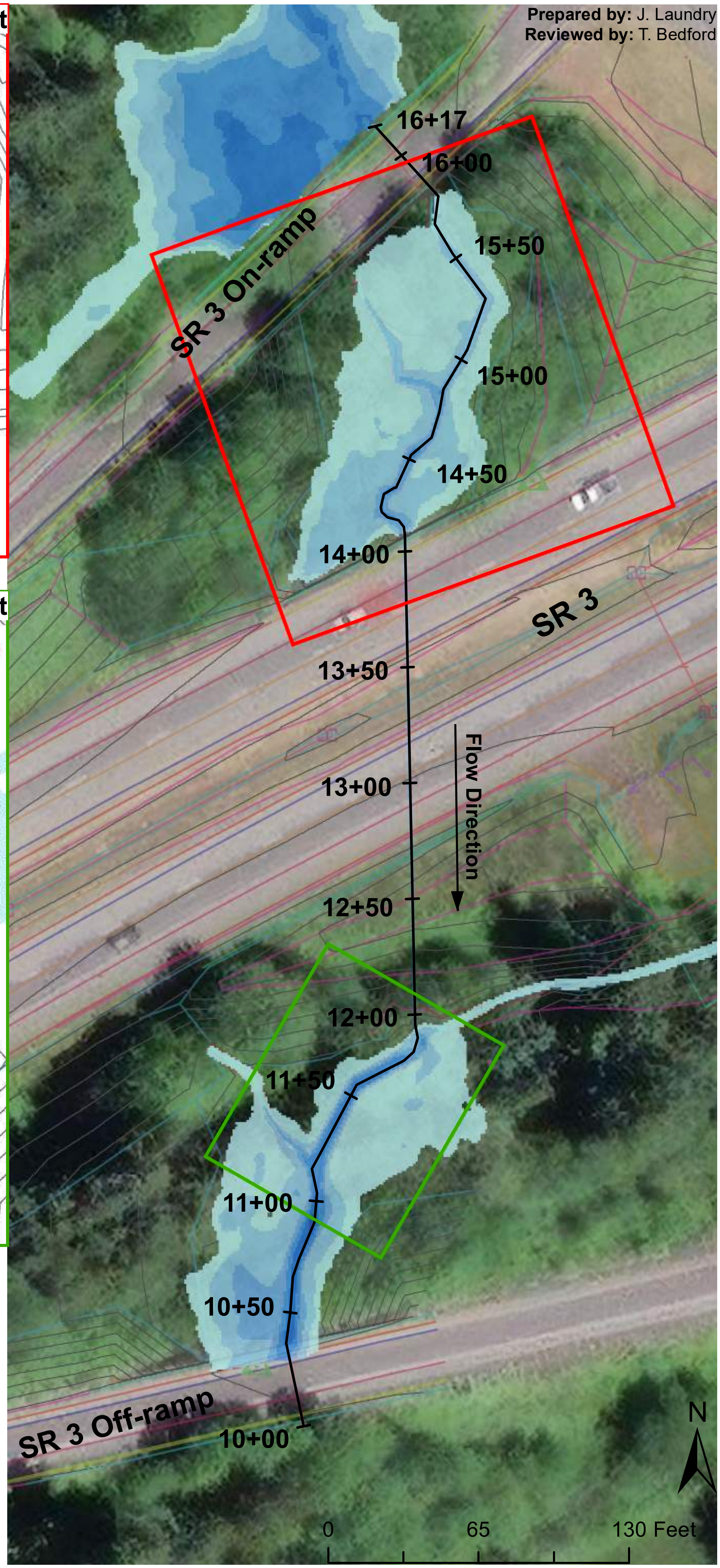
*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

Natural Conditions, 500yr Depth

Depth (ft)

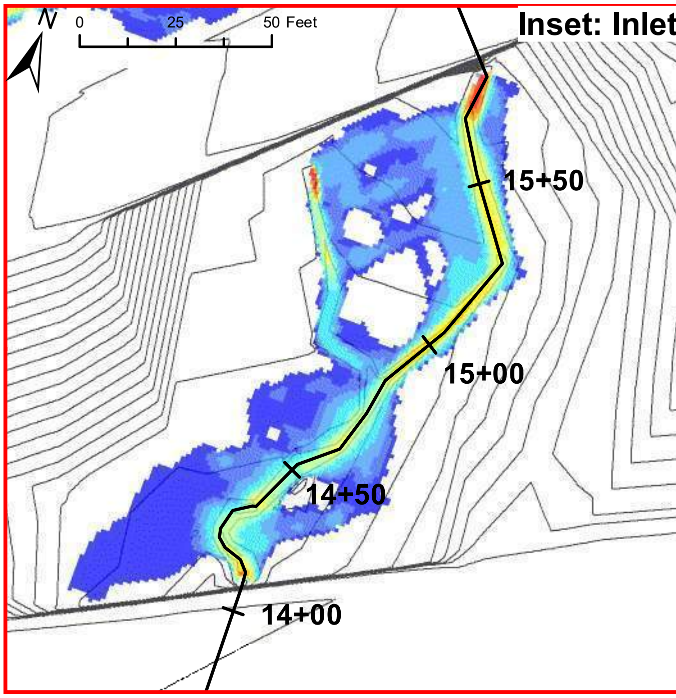
- < 1
- 1.0 - 2
- 2.0 - 3
- 3.0 - 4
- 4.0 - 5
- 5.0 - 10
- 10.0 - 15
- > 15.0

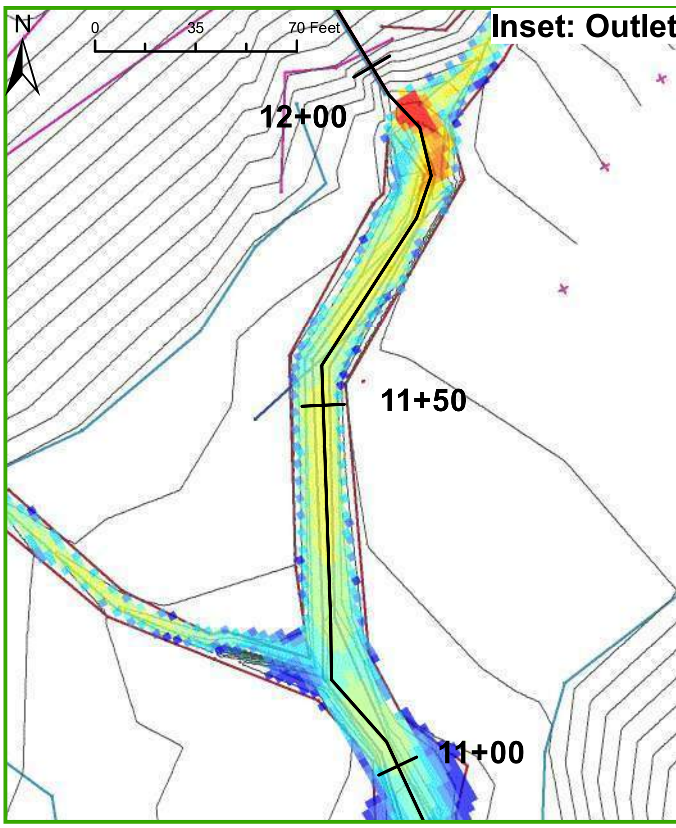
Prepared by: J. Laundry
Reviewed by: T. Bedford

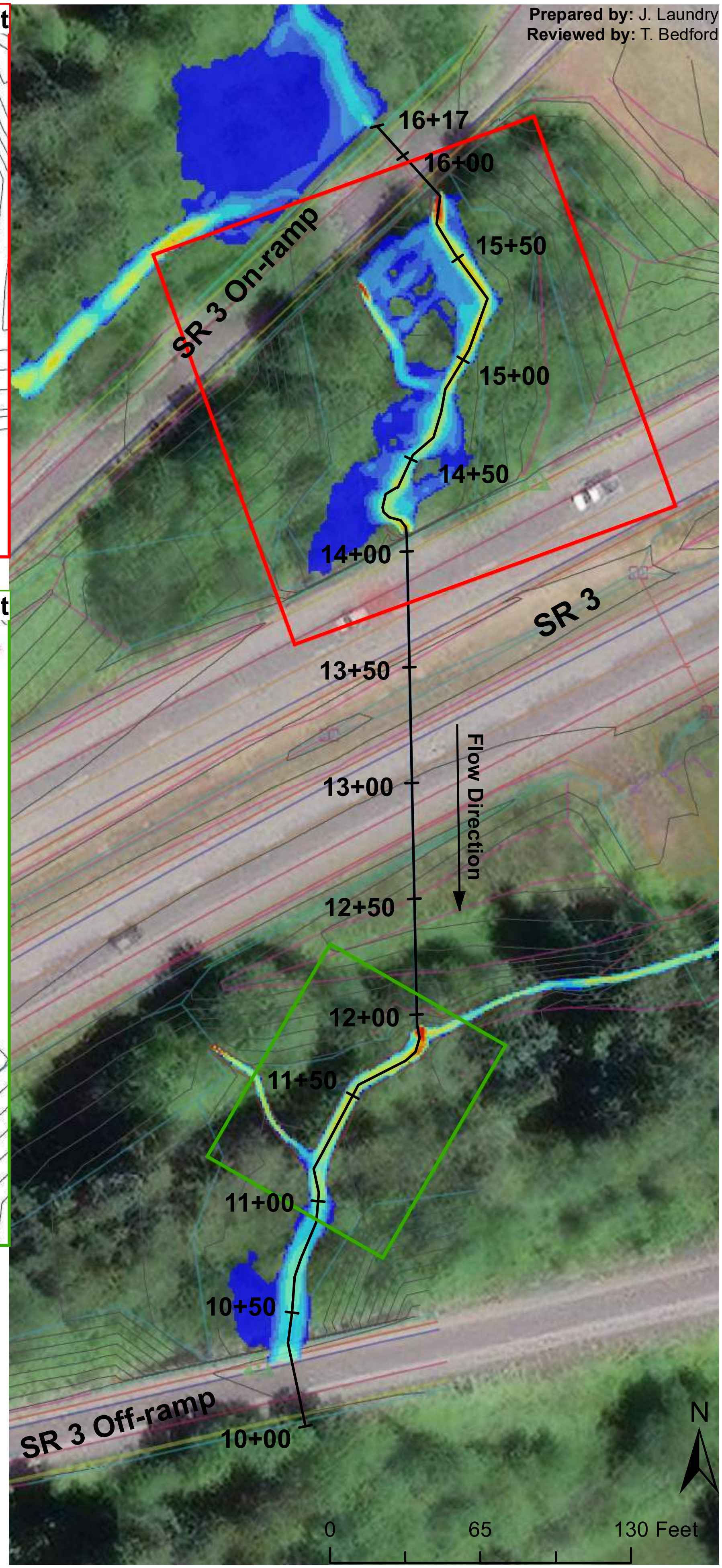


Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs





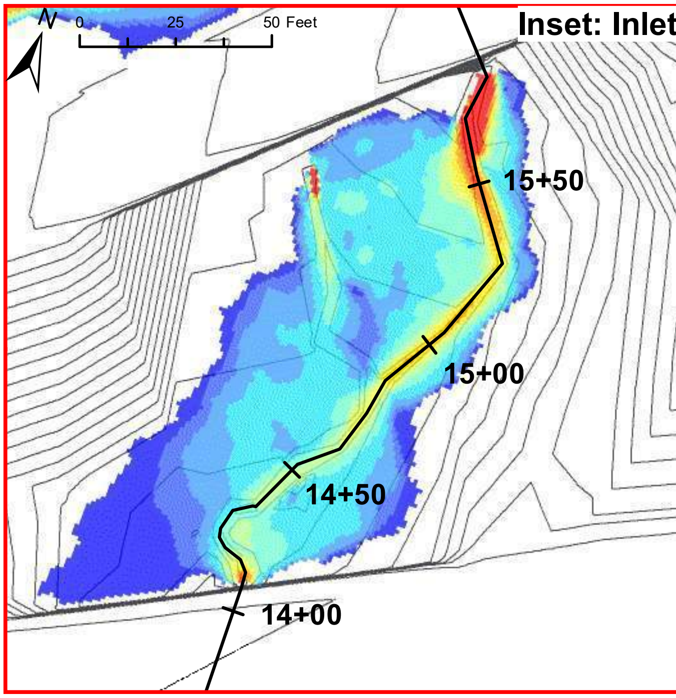


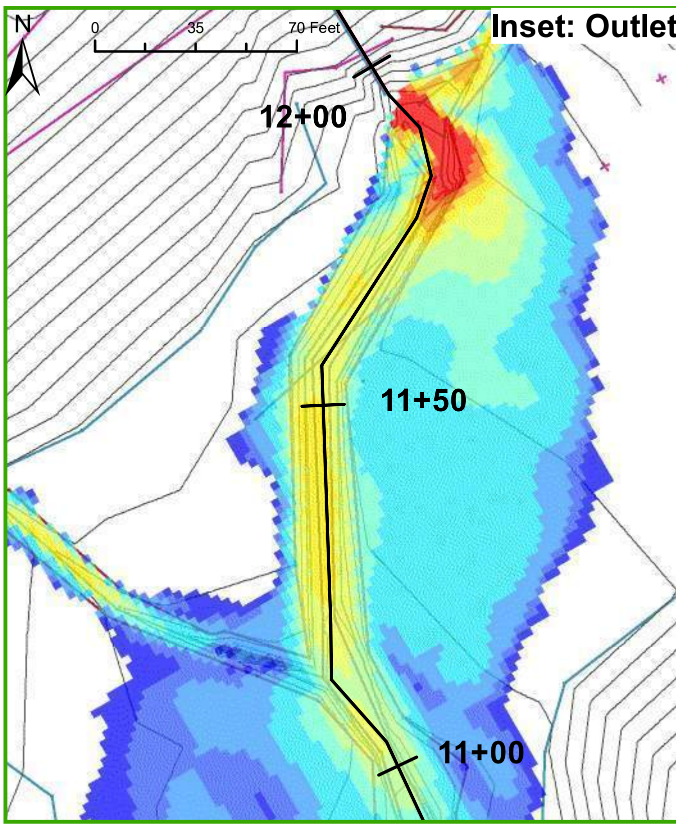
*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

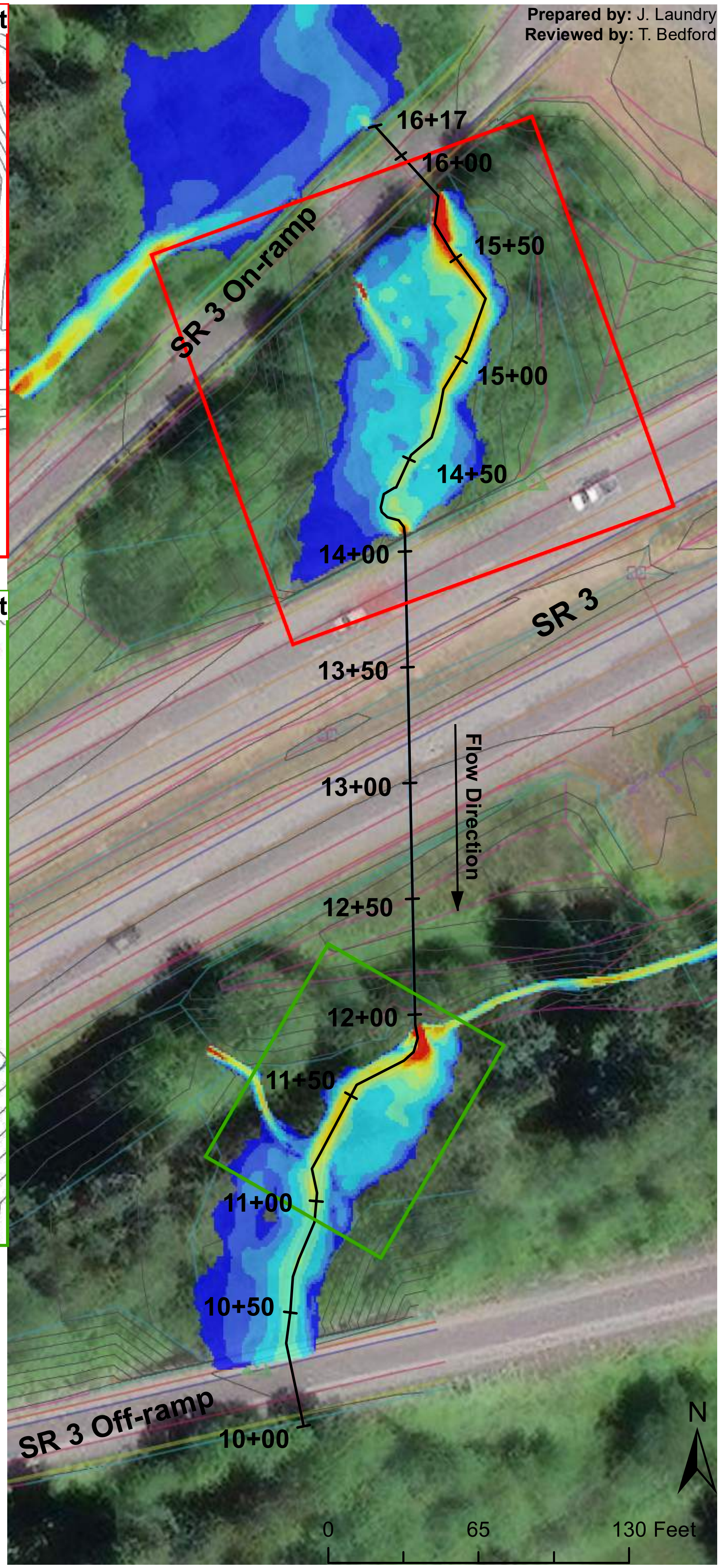
Natural Conditions, 2yr Velocity

Velocity (fps)

- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 2
- 2.0 - 3
- 3.01 - 4
- 4.0 - 5
- 5.0 - 6
- 6.0 - 7
- 7.0 - 8
- 8.0 - 9







*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

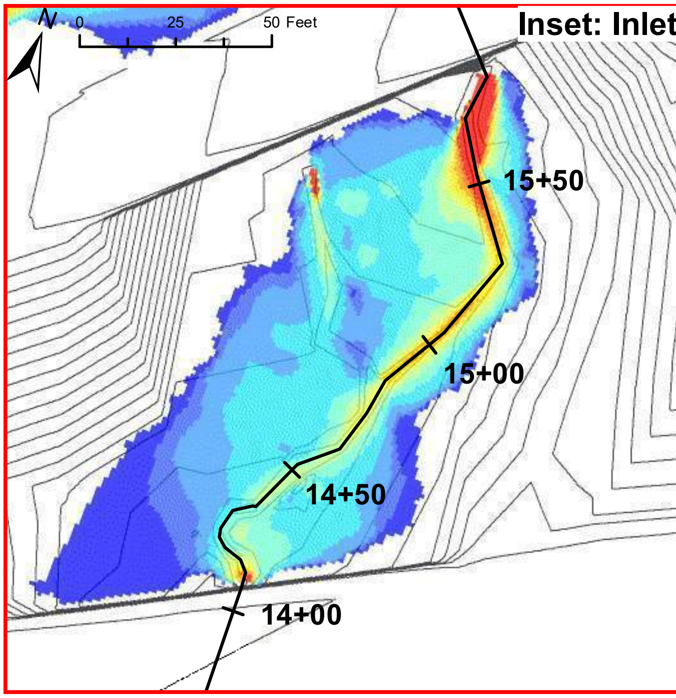
Natural Conditions, 100yr Velocity

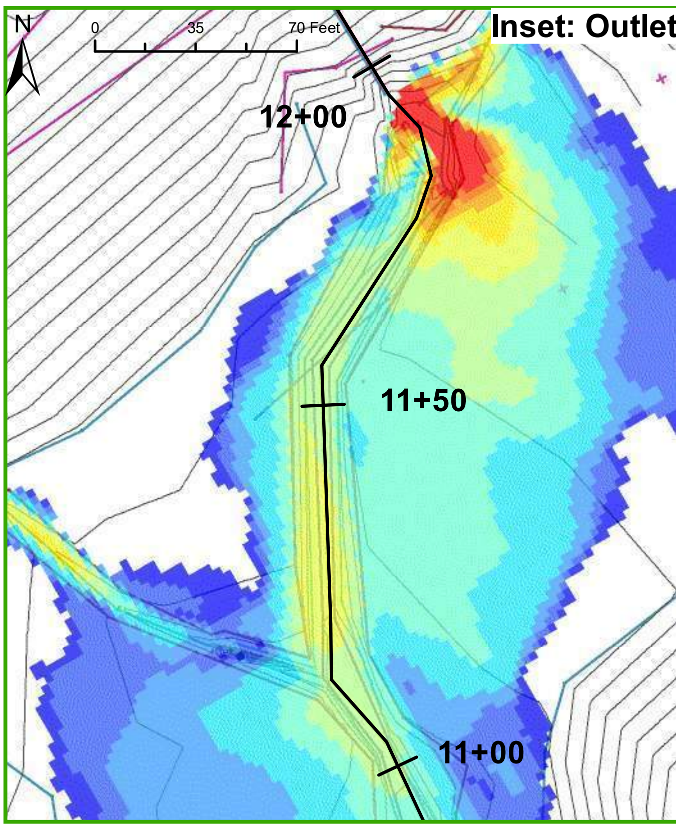
Velocity (fps)

- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 2
- 2.0 - 3
- 3.01 - 4
- 4.0 - 5
- 5.0 - 6
- 6.0 - 7
- 7.0 - 8
- 8.0 - 9

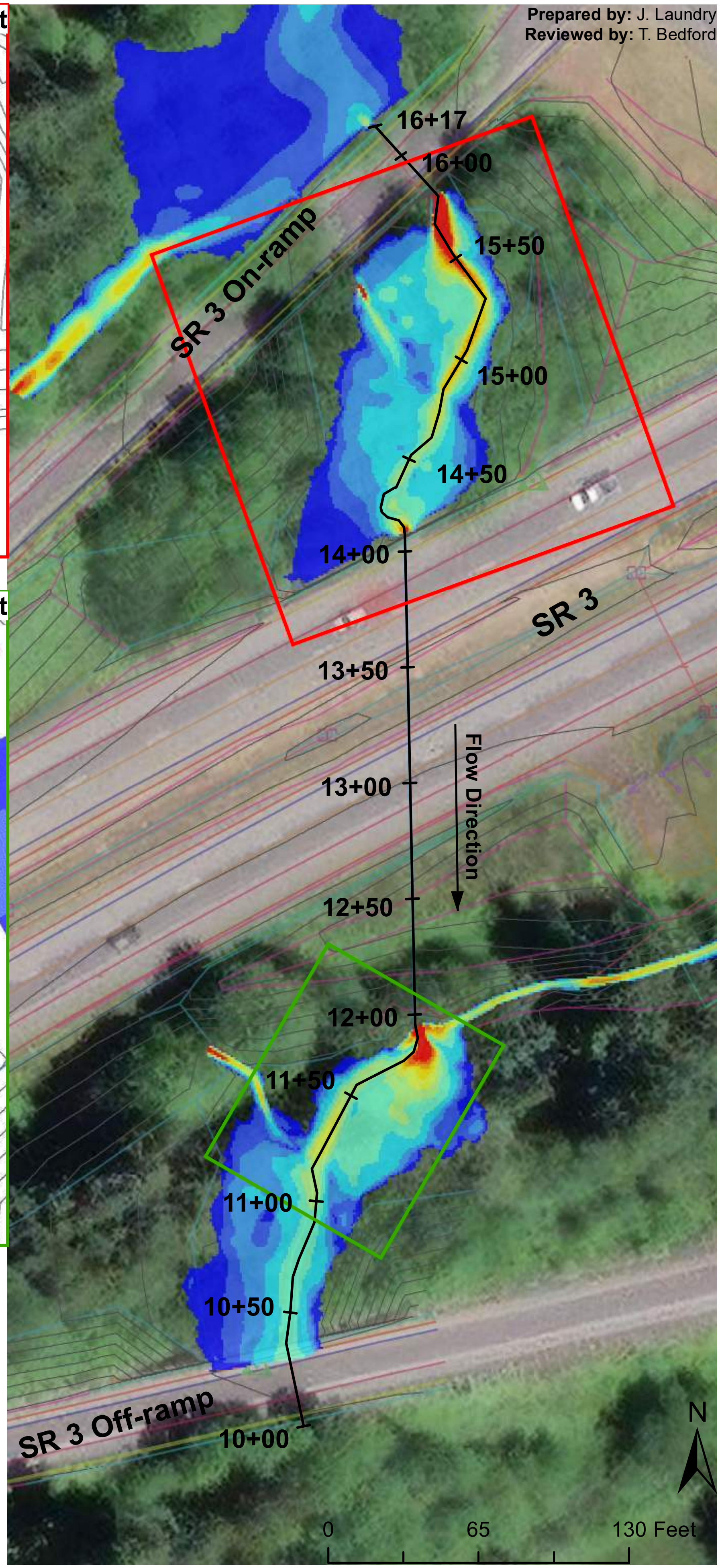
Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs





*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D



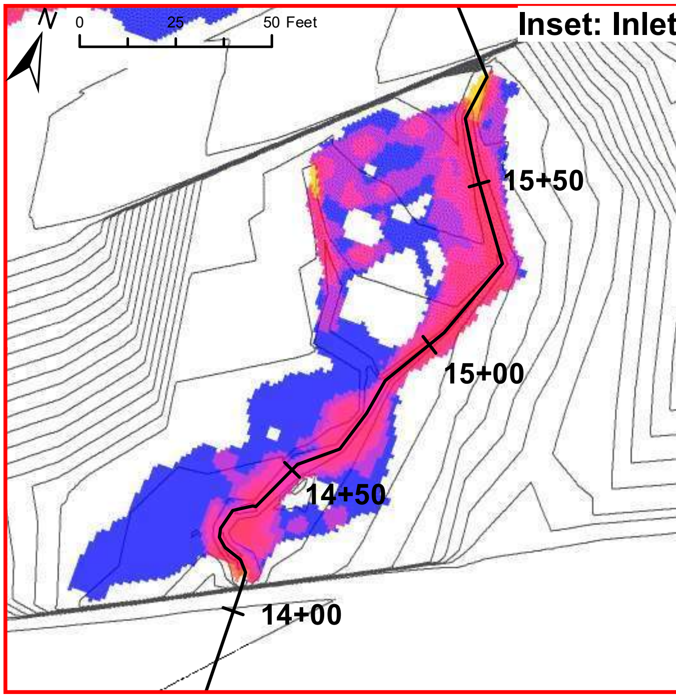
Natural Conditions, 500yr Velocity

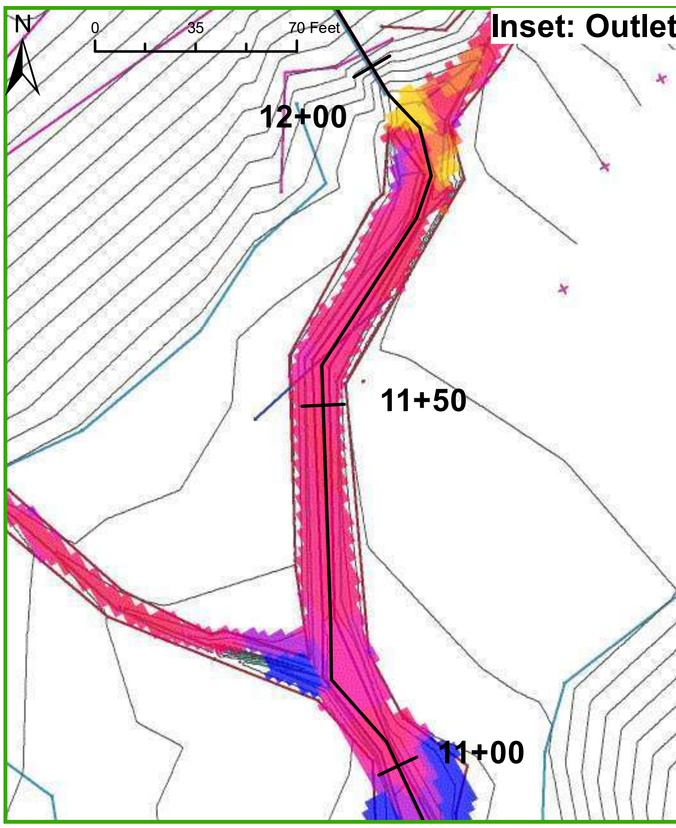
Velocity (fps)

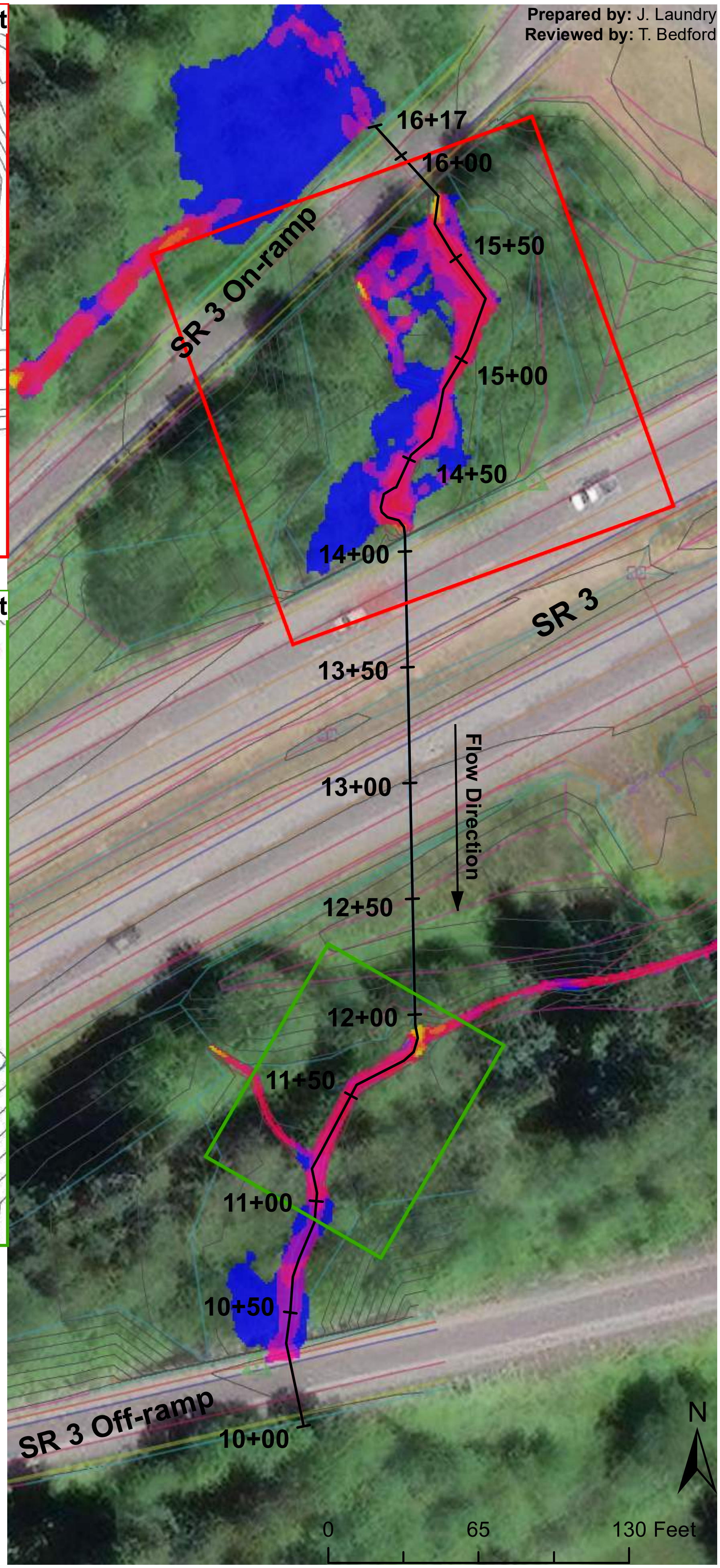
- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 2
- 2.0 - 3
- 3.01 - 4
- 4.0 - 5
- 5.0 - 6
- 6.0 - 7
- 7.0 - 8
- 8.0 - 9

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

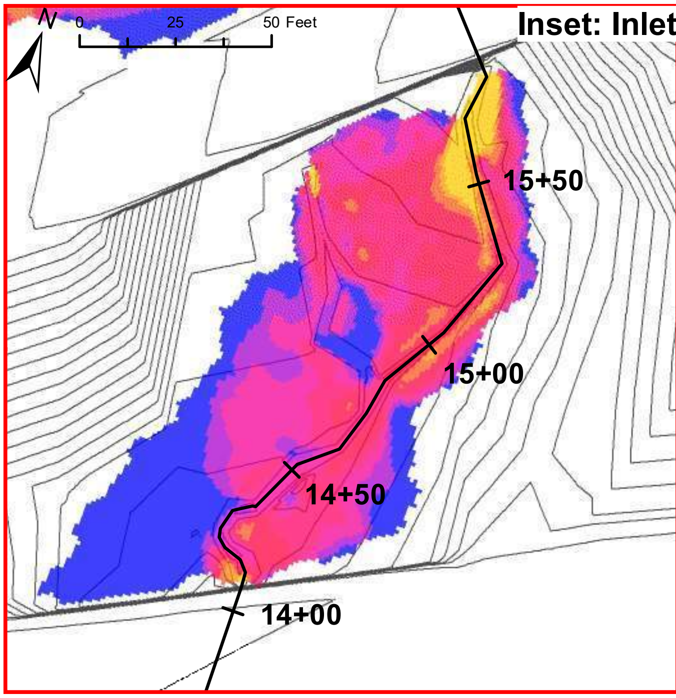
Natural Conditions, 2yr Shear Stress

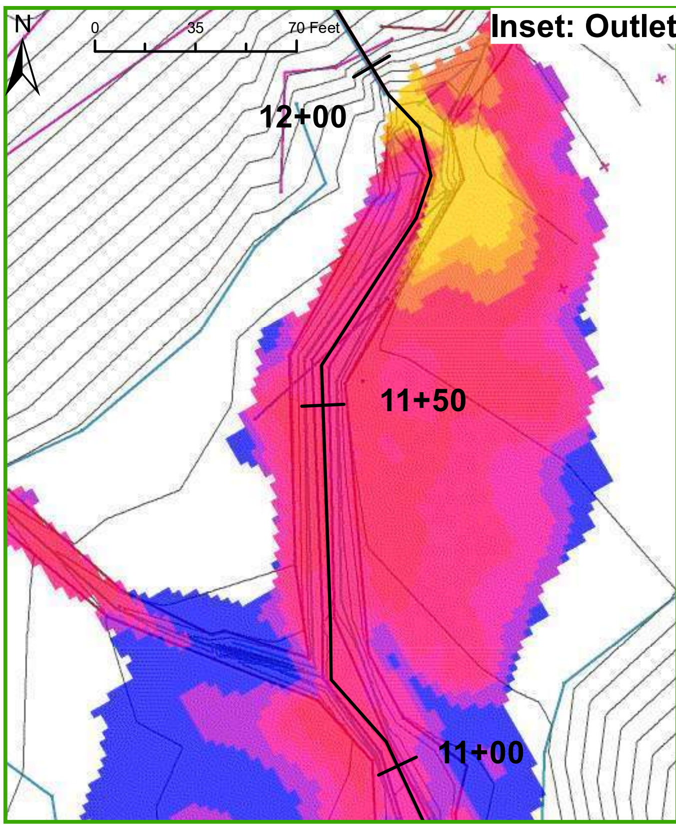
Shear Stress (psf)

- 0 - 0.1
- 0.10 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- > 4

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs



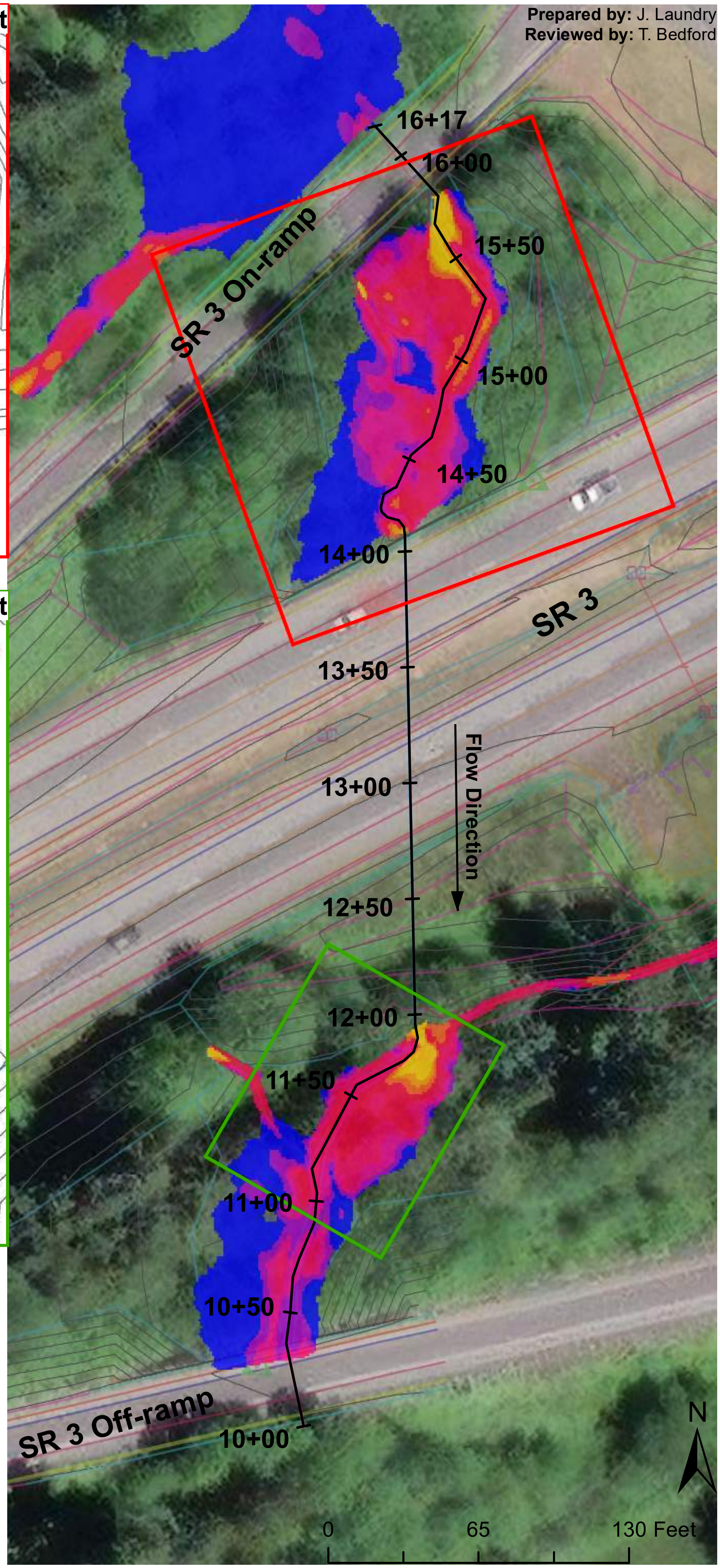


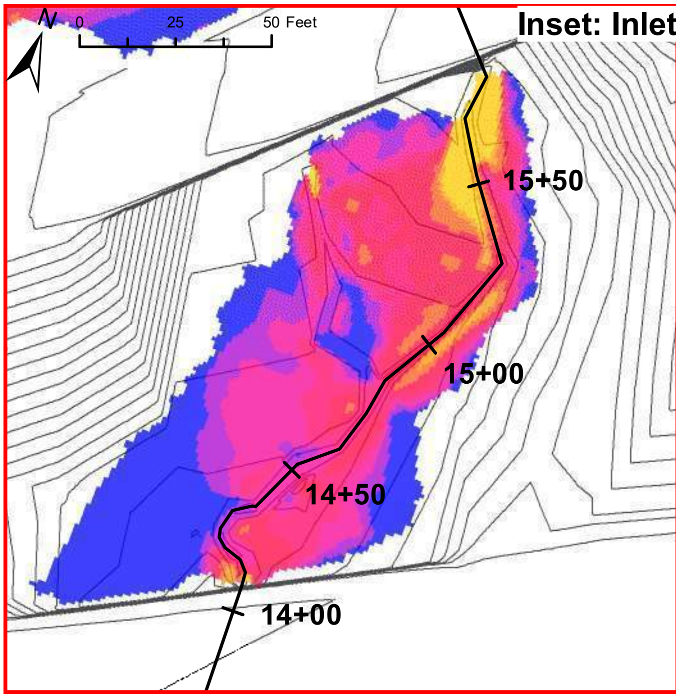
*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

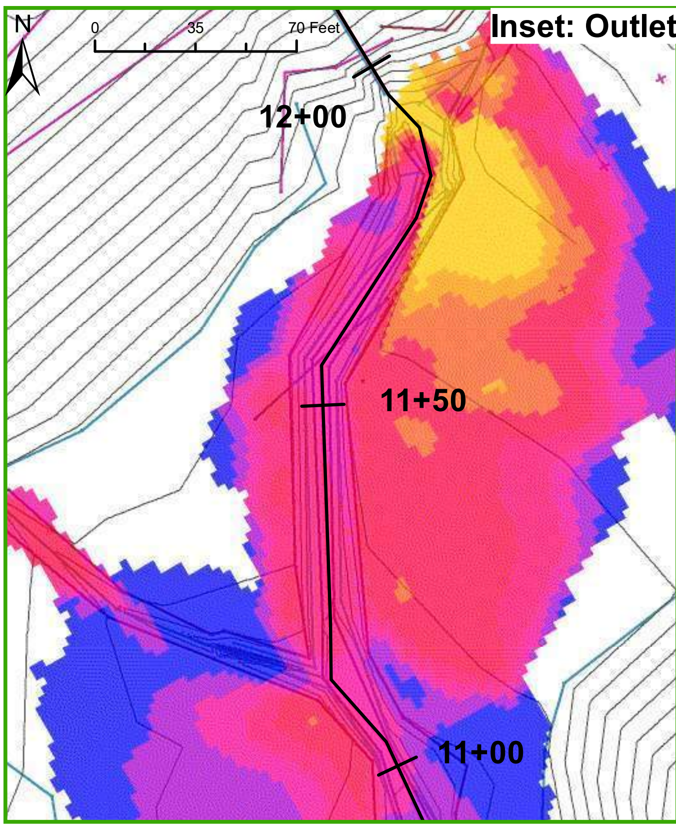
Natural Conditions, 100yr Shear Stress

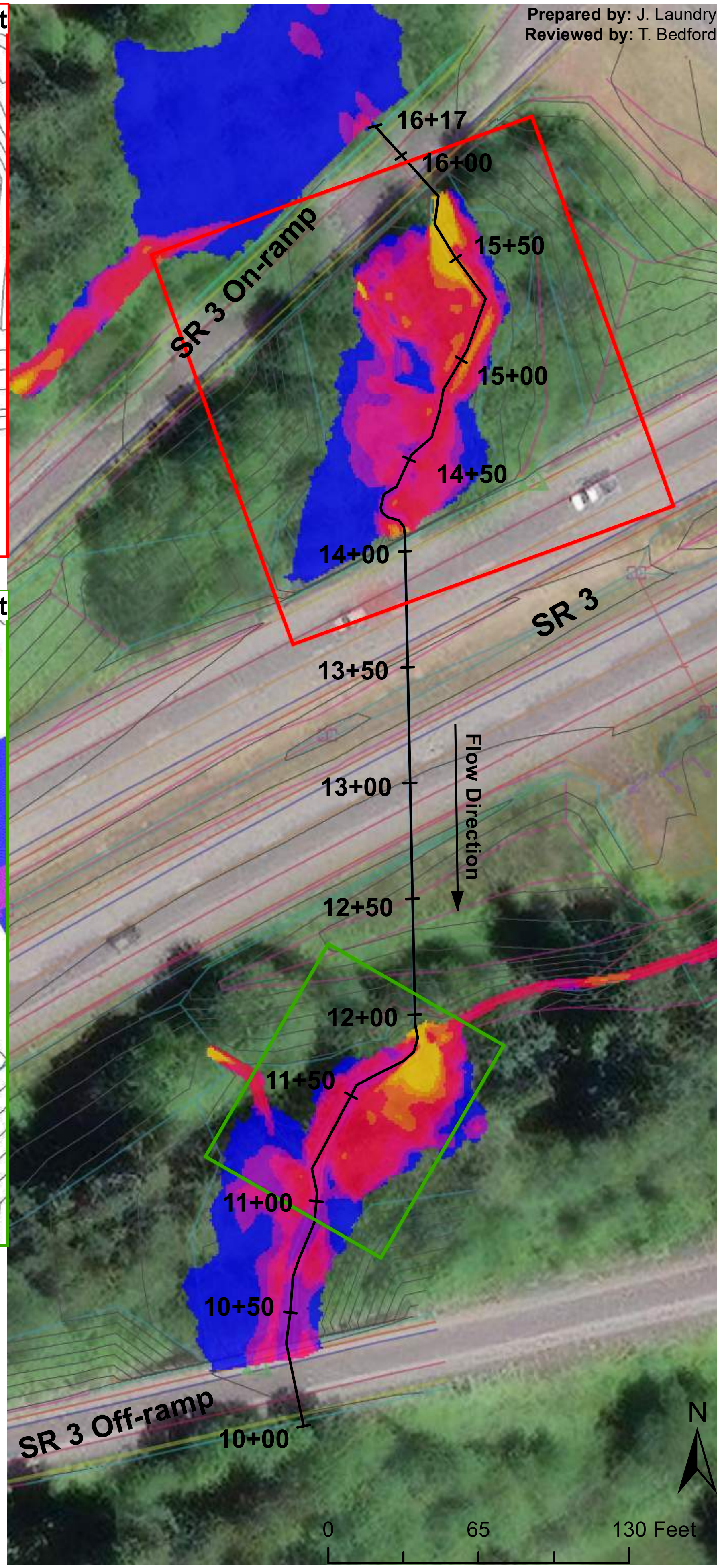
Shear Stress (psf)

0 - 0.1	0.5 - 1	3 - 4
0.10 - 0.25	1 - 2	> 4
0.25 - 0.5	2 - 3	









*Alignment shown cooresponds to alignment on Sheet CE1 in Appendix D

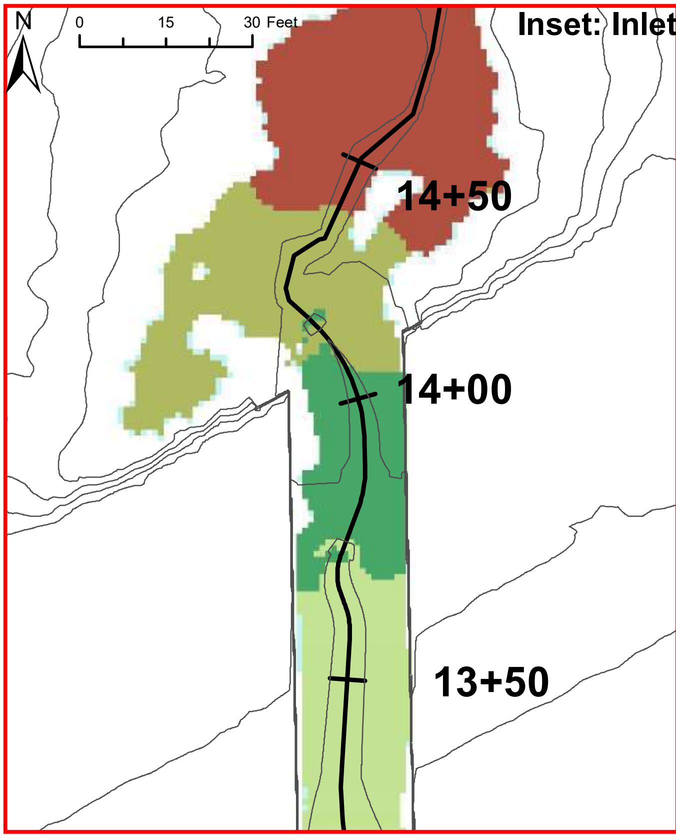
Natural Conditions, 500yr Shear Stress

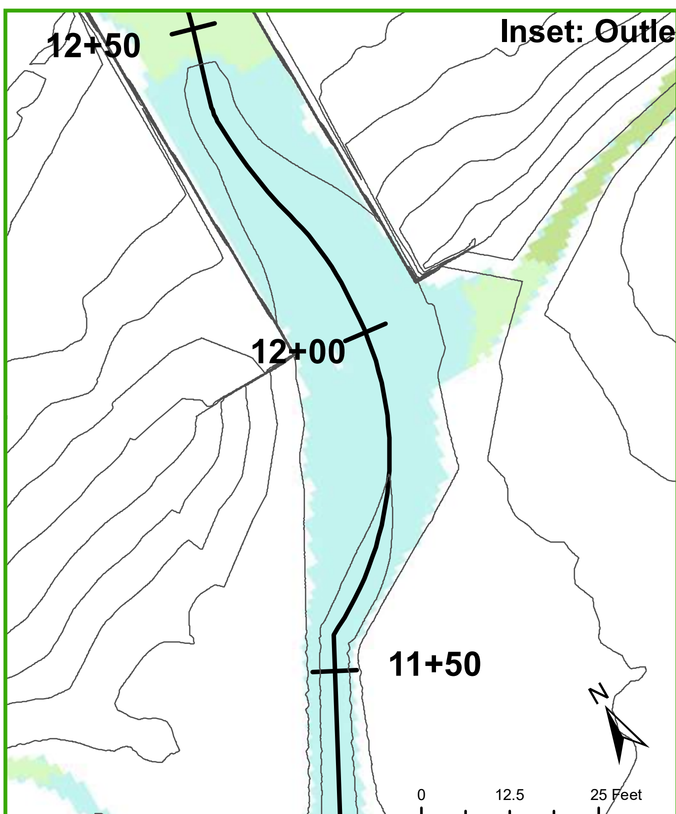
Shear Stress (psf)

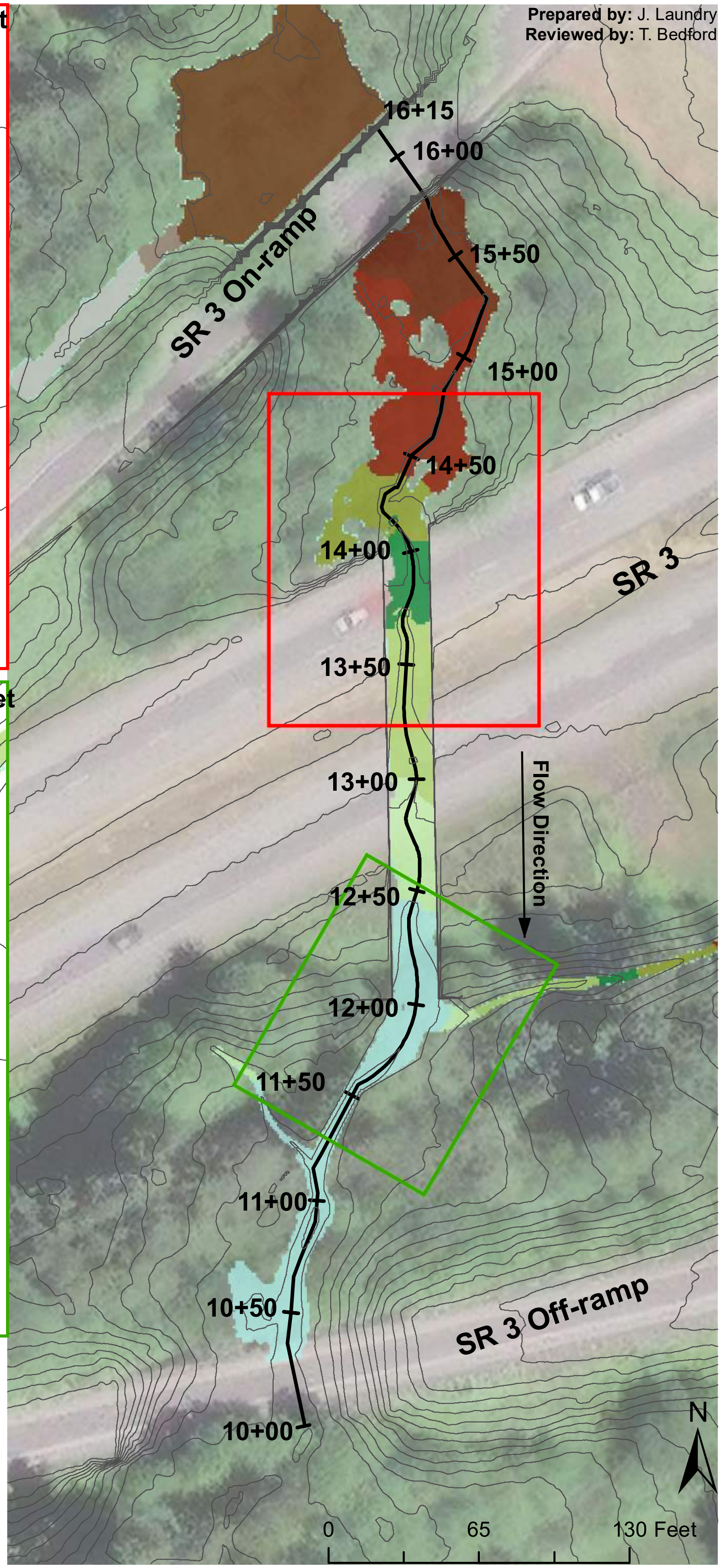
- 0 - 0.1
- 0.10 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- > 4

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







Proposed Conditions, 2yr Water Surface Elevation

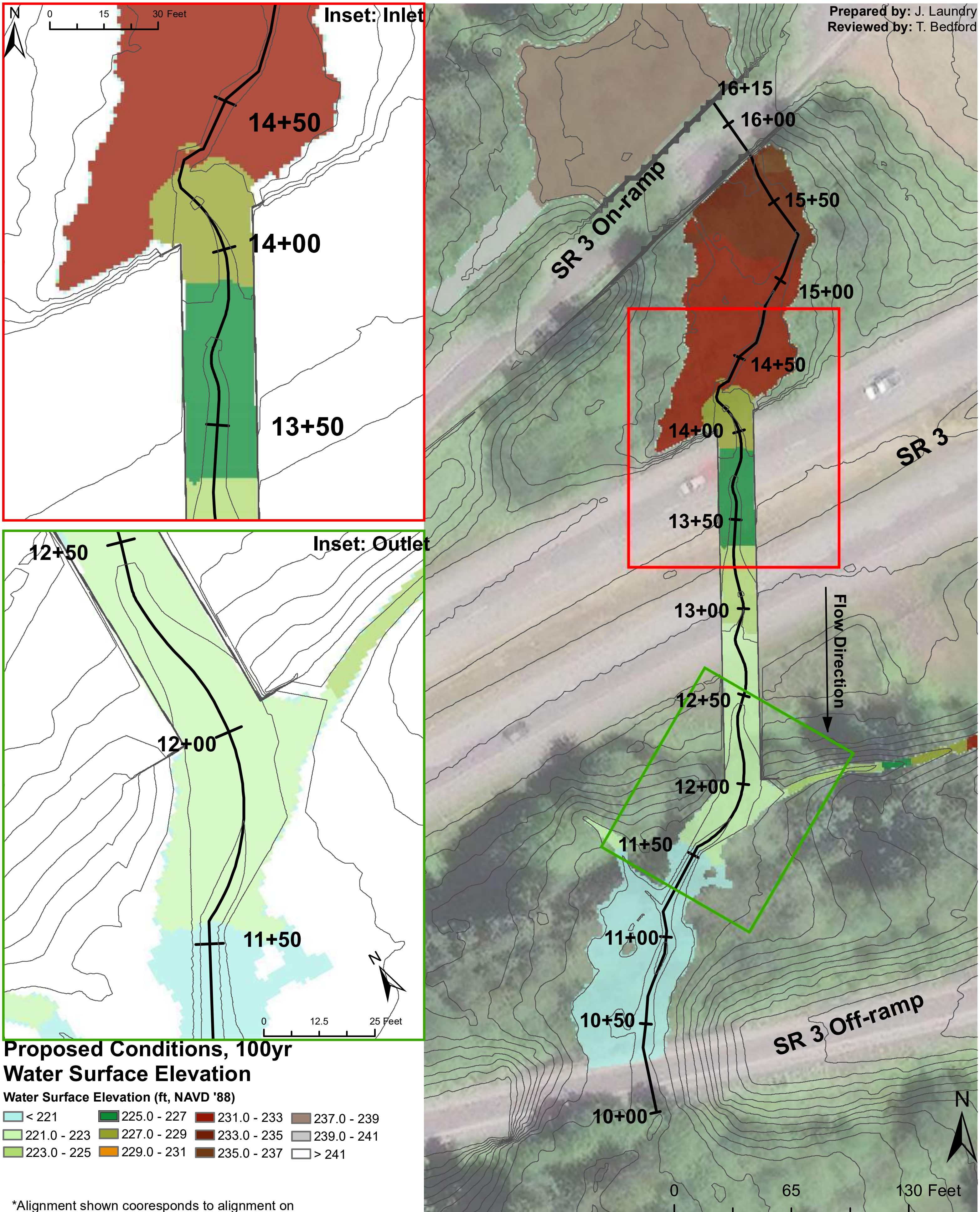
Water Surface Elevation (ft, NAVD '88)

< 221	225.0 - 227	231.0 - 233	237.0 - 239
221.0 - 223	227.0 - 229	233.0 - 235	239.0 - 241
223.0 - 225	229.0 - 231	235.0 - 237	> 241

*Alignment shown cooresponds to alignment on Sheet CR1 in Appendix D

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs



Proposed Conditions, 100yr Water Surface Elevation

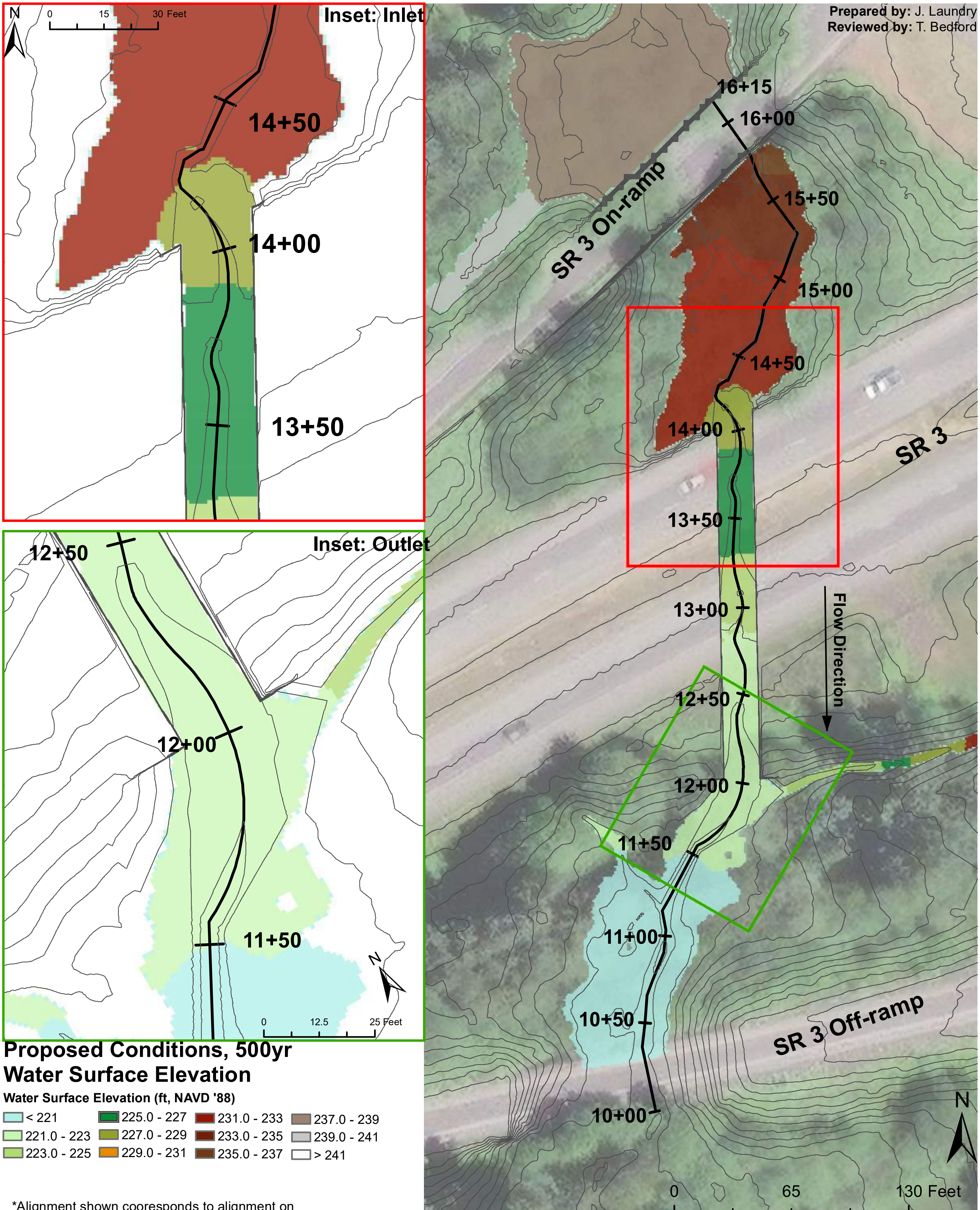
Water Surface Elevation (ft, NAVD '88)

- < 221
- 221.0 - 223
- 223.0 - 225
- 225.0 - 227
- 227.0 - 229
- 229.0 - 231
- 231.0 - 233
- 233.0 - 235
- 235.0 - 237
- 237.0 - 239
- 239.0 - 241
- > 241

*Alignment shown cooresponds to alignment on Sheet CR1 in Appendix D

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs



Proposed Conditions, 500yr Water Surface Elevation

Water Surface Elevation (ft, NAVD '88)

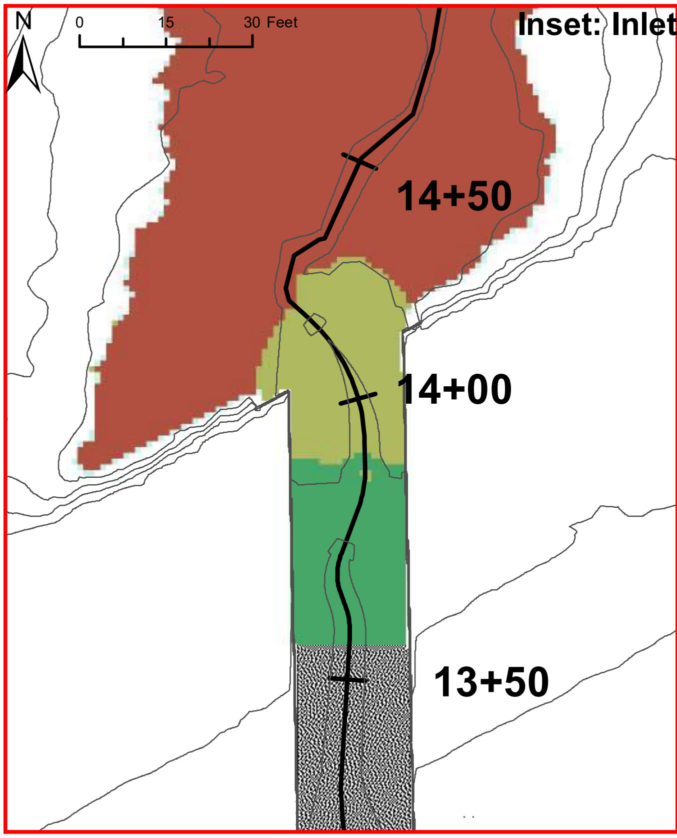
- < 221
- 221.0 - 223
- 223.0 - 225
- 225.0 - 227
- 227.0 - 229
- 229.0 - 231
- 231.0 - 233
- 233.0 - 235
- 235.0 - 237
- 237.0 - 239
- 239.0 - 241
- > 241

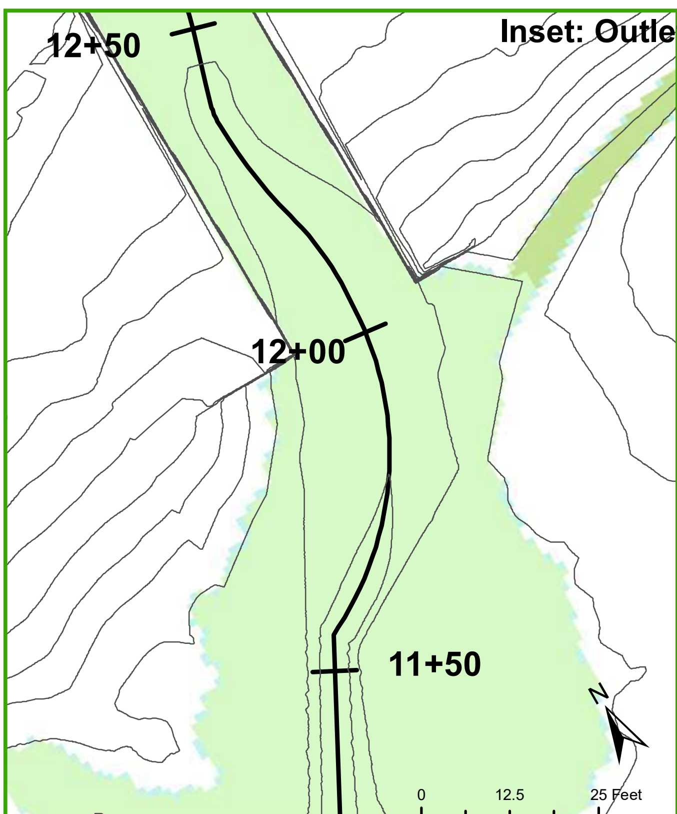
*Alignment shown cooresponds to alignment on Sheet CR1 in Appendix D

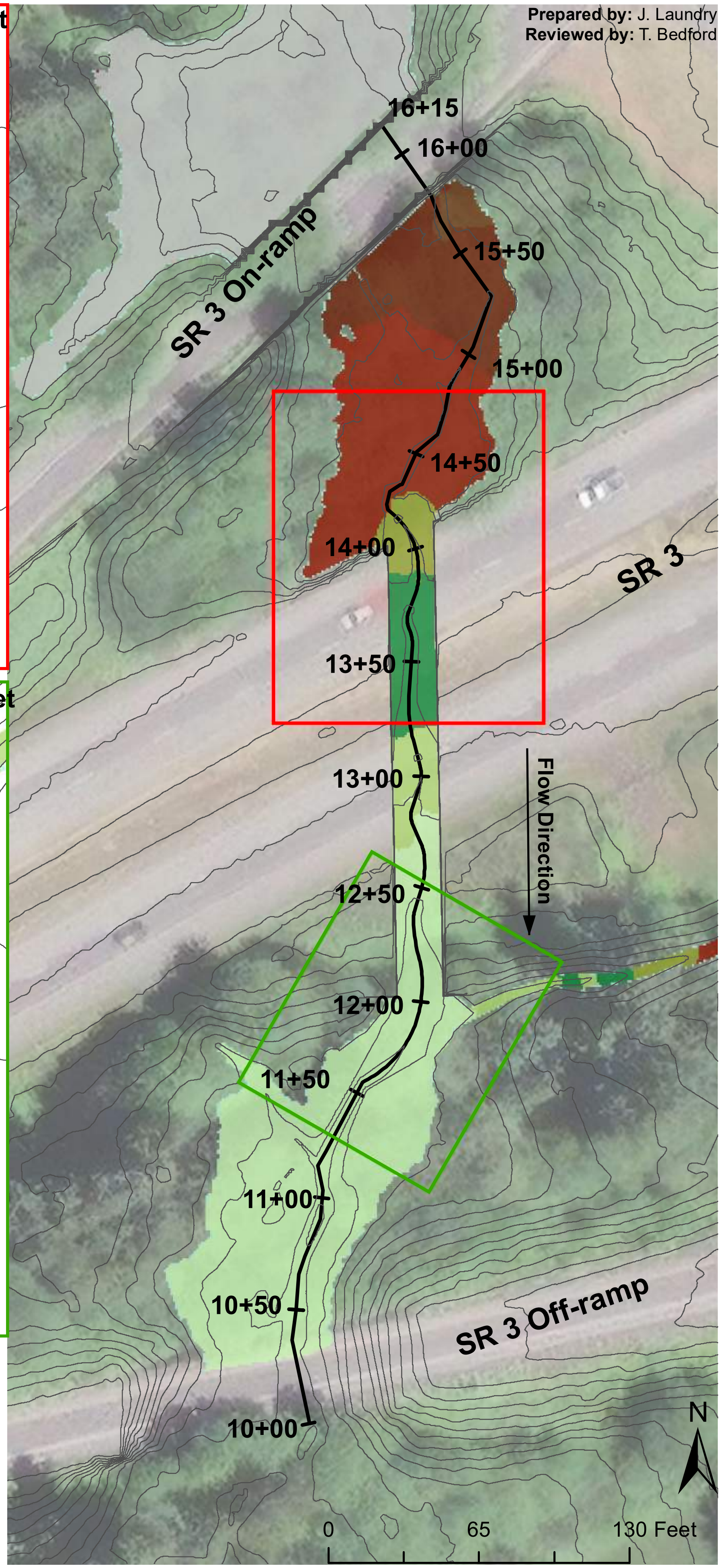
Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs

Prepared by: J. Laundry
Reviewed by: T. Bedford





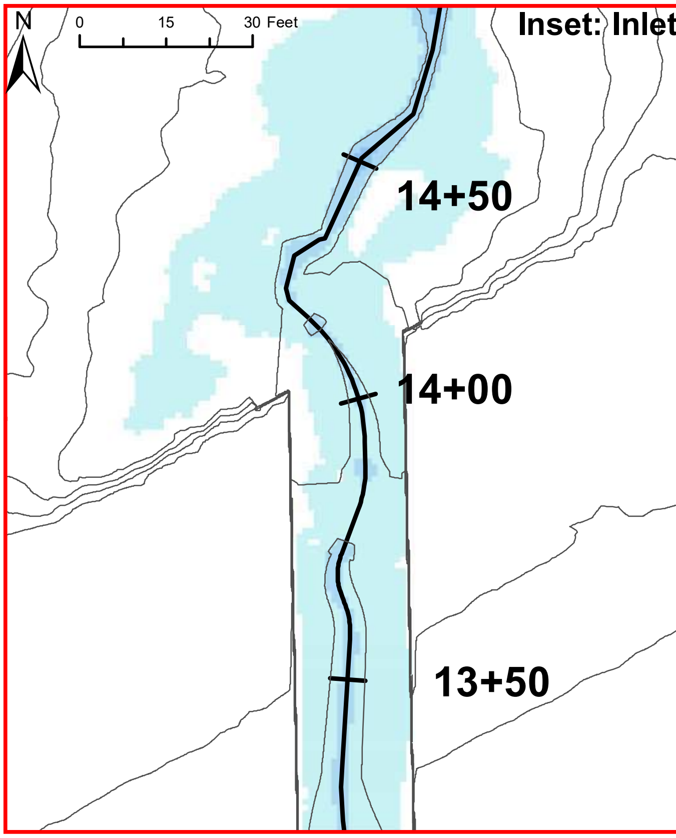


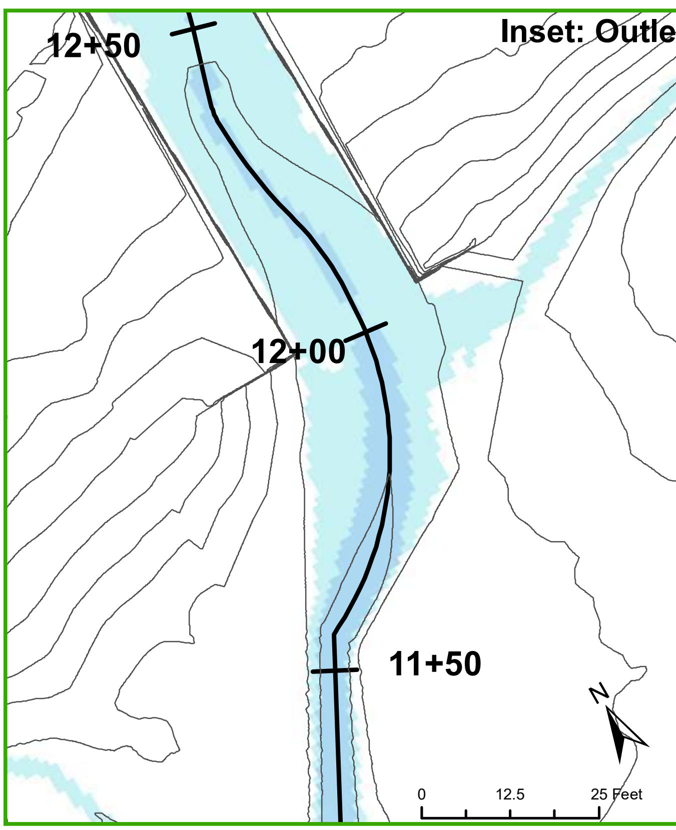
Proposed Conditions, Projected 2080 100yr Water Surface Elevation

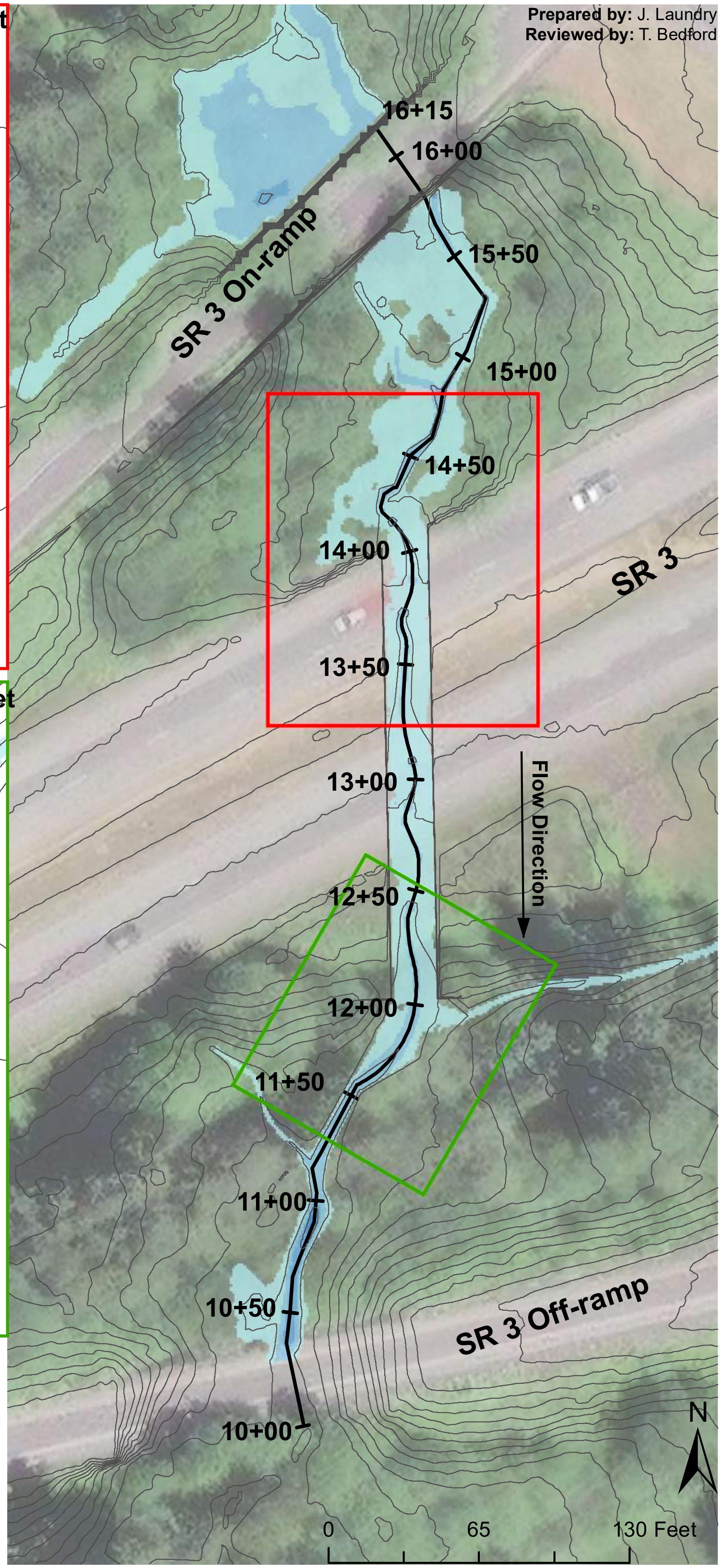
Water Surface Elevation (ft, NAVD '88)

- < 221
- 221.0 - 223
- 223.0 - 225
- 225.0 - 227
- 227.0 - 229
- 229.0 - 231
- 231.0 - 233
- 233.0 - 235
- 235.0 - 237
- 237.0 - 239
- 239.0 - 241
- > 241

*Alignment shown cooresponds to alignment on Sheet CR1 in Appendix D







Proposed Conditions, 2yr Depth

Depth (ft)

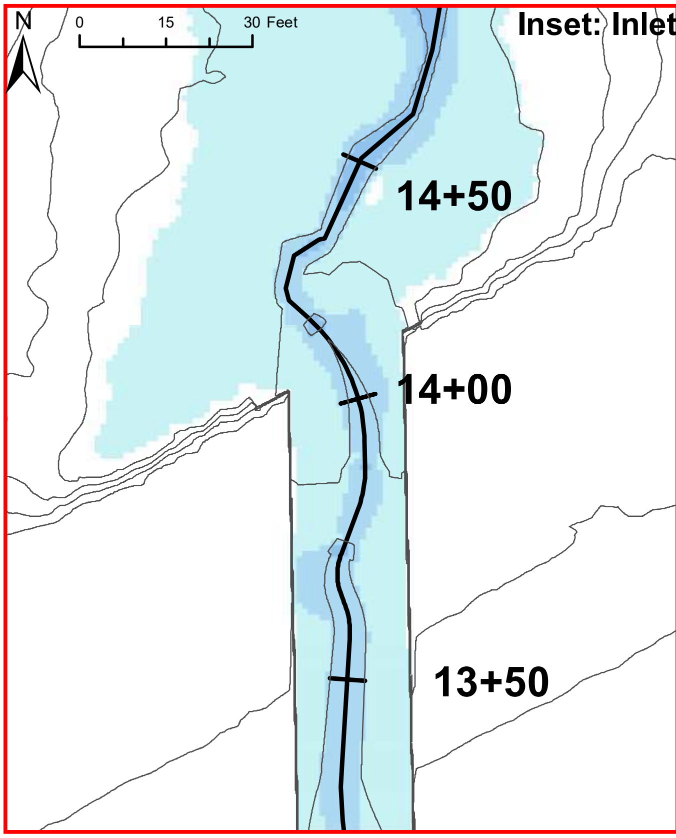
- < 1
- 1.0 - 2
- 2.0 - 3
- 3.0 - 4
- 4.0 - 5
- 5.0 - 10
- 10.0 - 15
- > 15.0

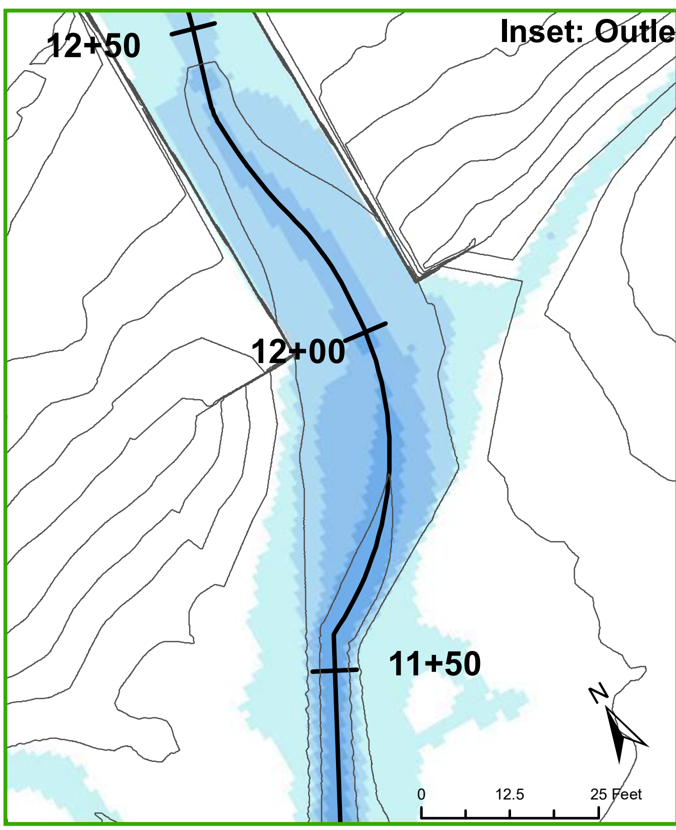
*Alignment shown cooresponds to alignment on Sheet CR1 in Appendix D

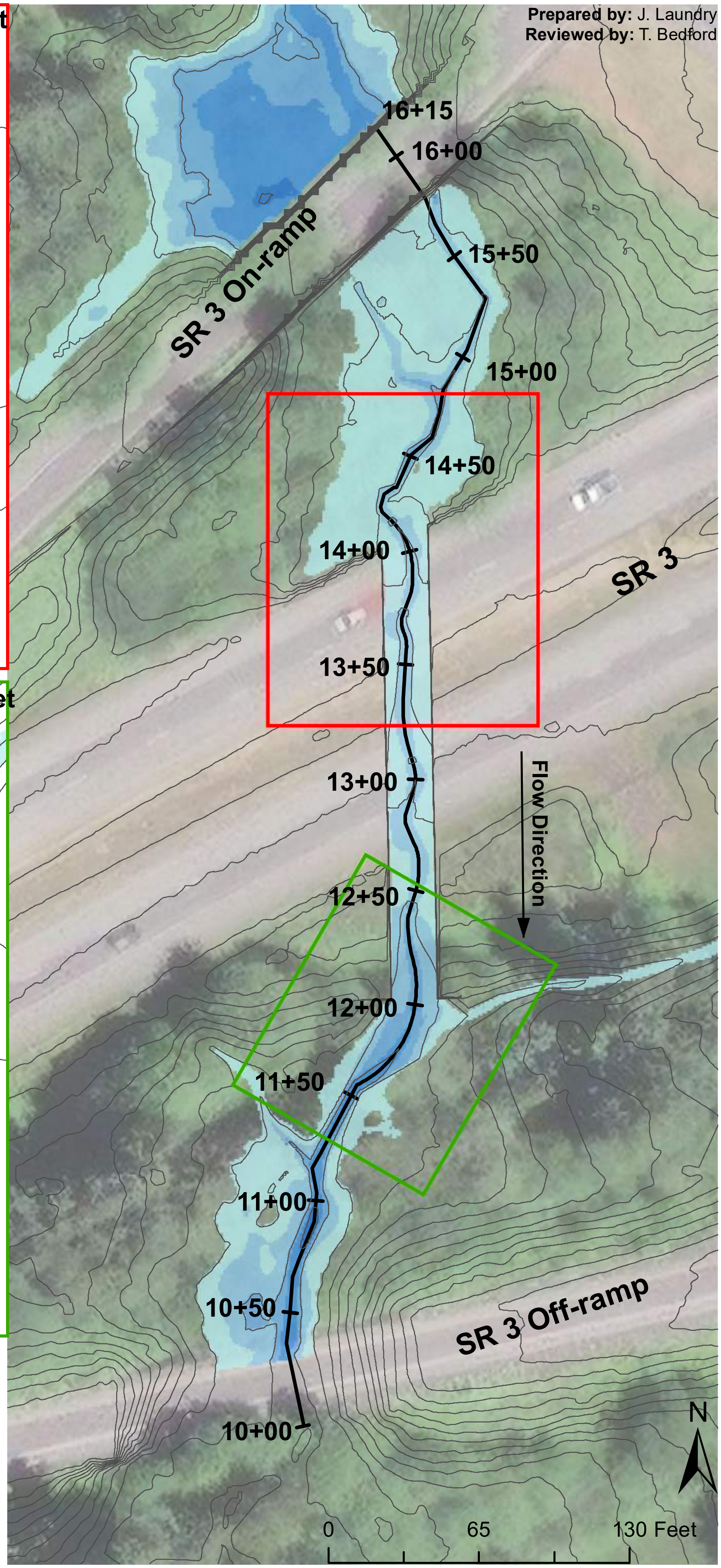
WSDOT OLYMPIC REGION GEC

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







Proposed Conditions, 100yr Depth

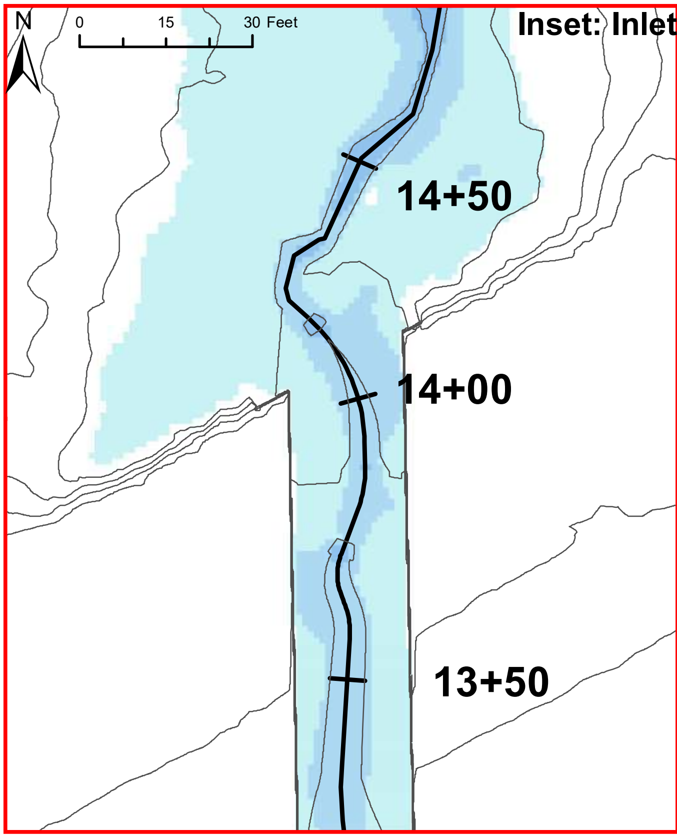
Depth (ft)

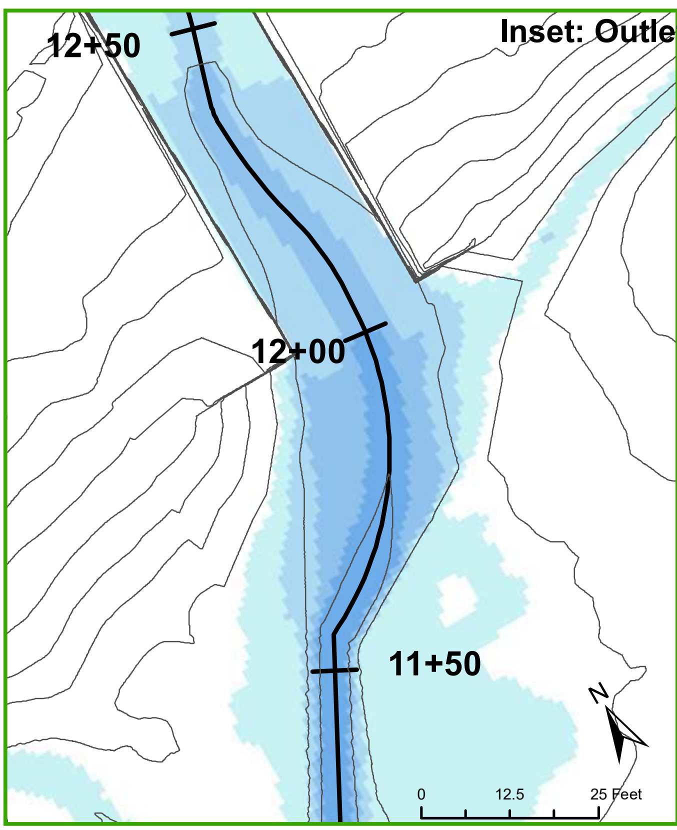
- < 1
- 1.0 - 2
- 2.0 - 3
- 3.0 - 4
- 4.0 - 5
- 5.0 - 10
- 10.0 - 15
- > 15.0

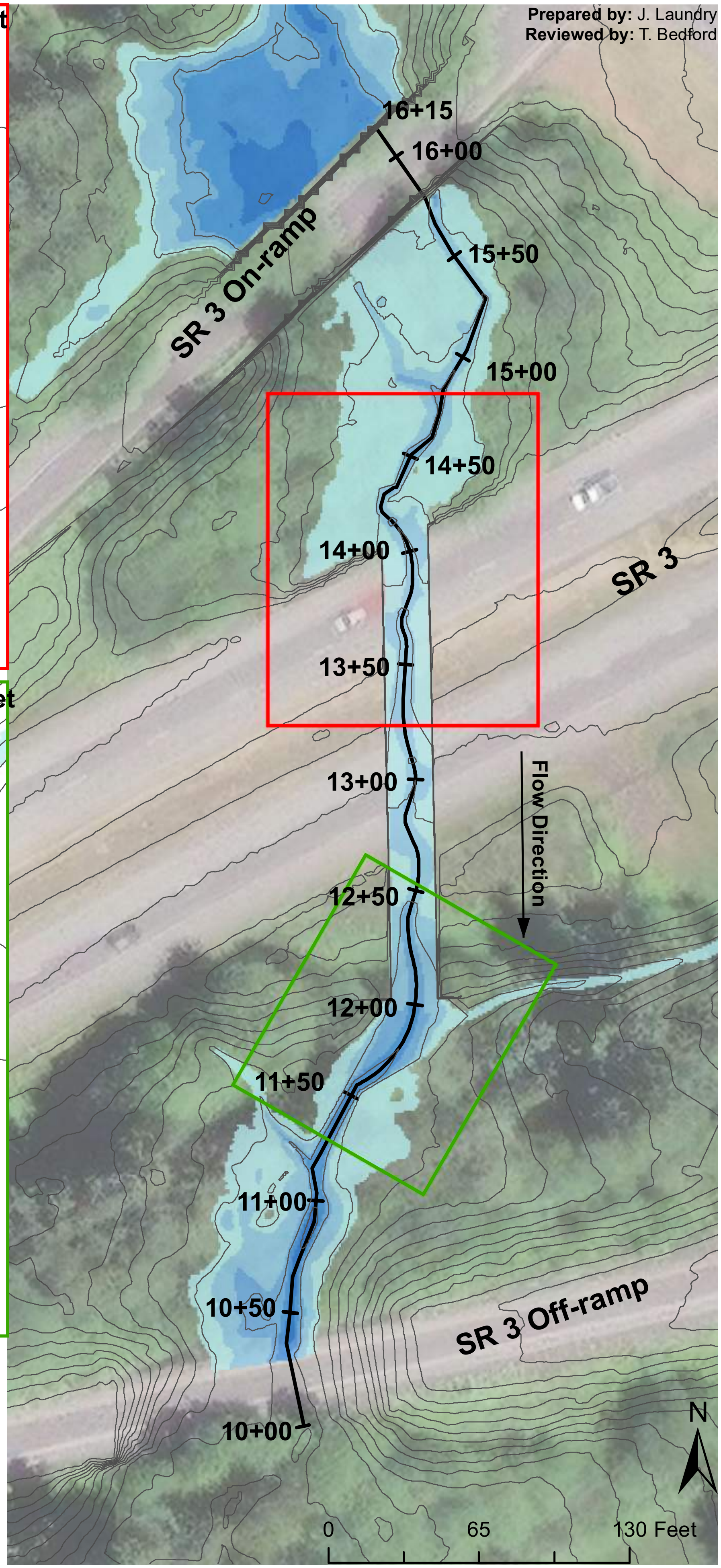
*Alignment shown cooresponds to alignment on Sheet CR1 in Appendix D

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







Proposed Conditions, 500yr Depth

Depth (ft)

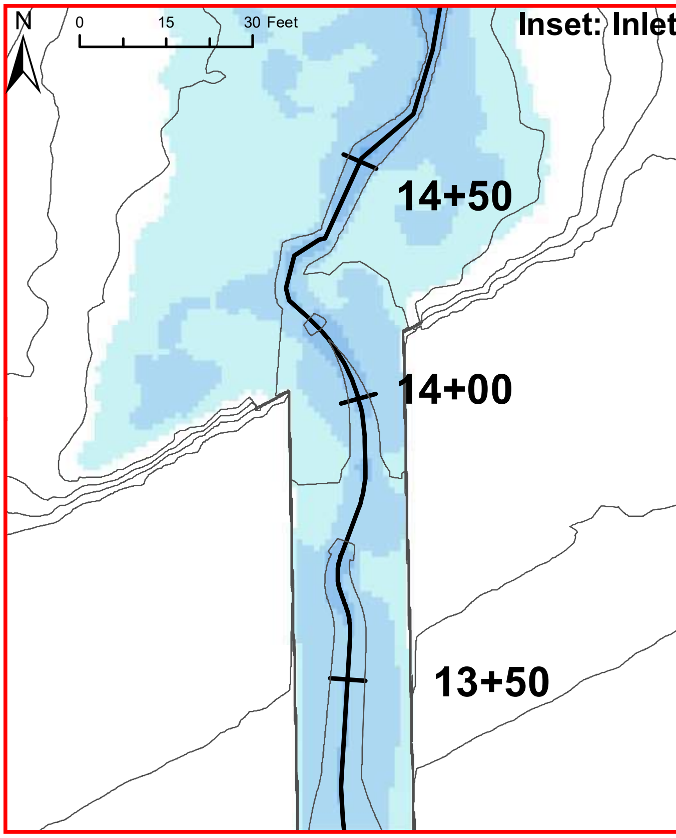
- < 1
- 1.0 - 2
- 2.0 - 3
- 3.0 - 4
- 4.0 - 5
- 5.0 - 10
- 10.0 - 15
- > 15.0

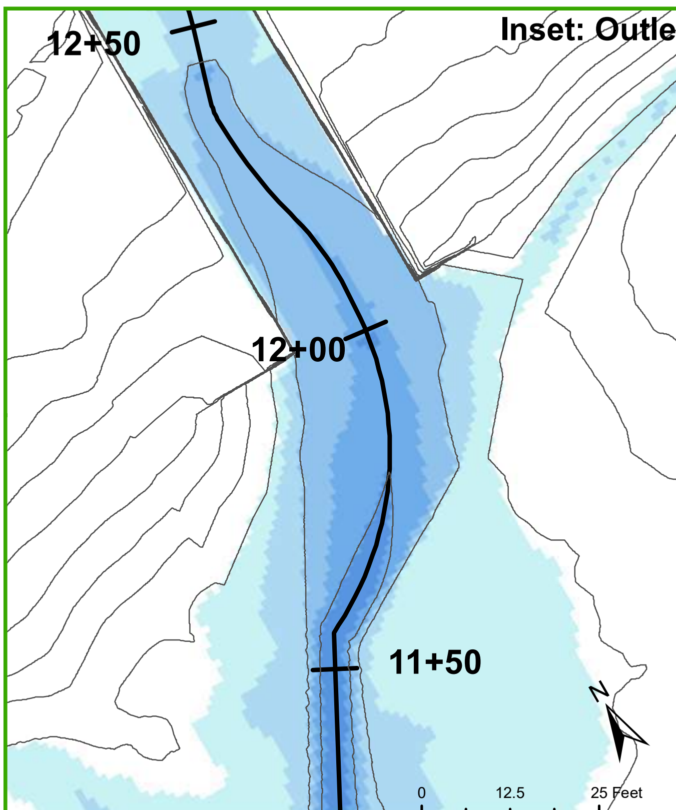
*Alignment shown cooresponds to alignment on Sheet CR1 in Appendix D

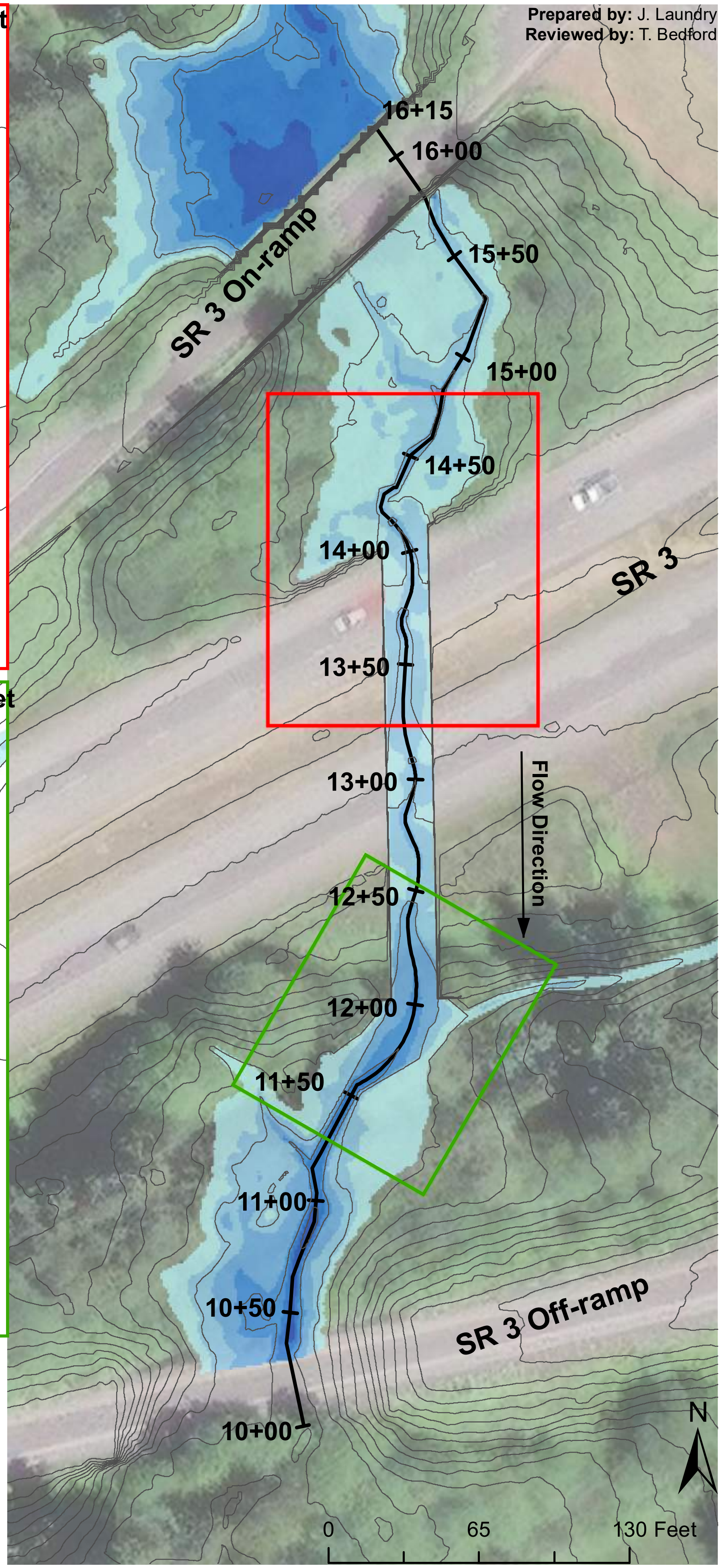
Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs

Prepared by: J. Laundry
Reviewed by: T. Bedford







Proposed Conditions, Projected 2080 100yr Depth

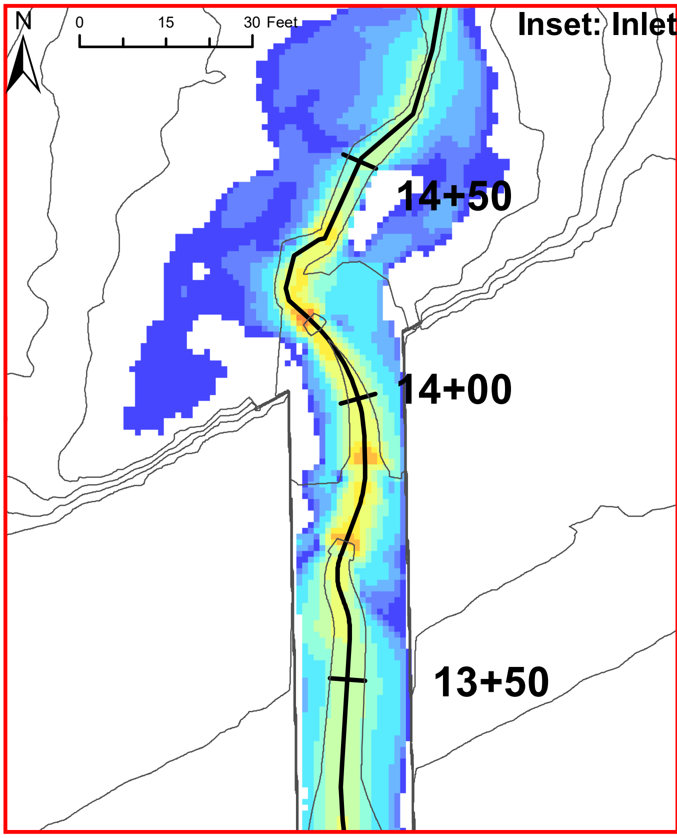
Depth (ft)

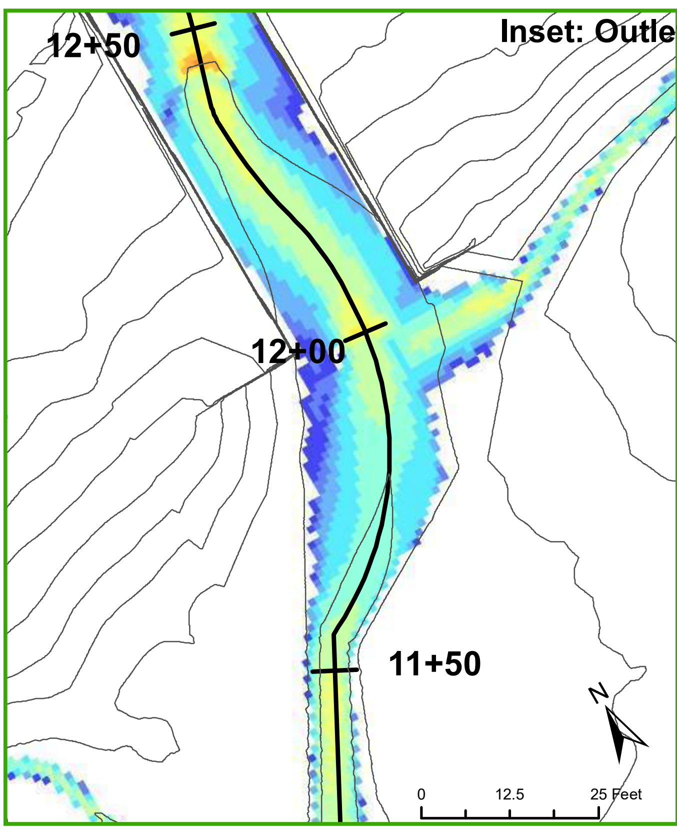
- < 1
- 1.0 - 2
- 2.0 - 3
- 3.0 - 4
- 4.0 - 5
- 5.0 - 10
- 10.0 - 15
- > 15.0

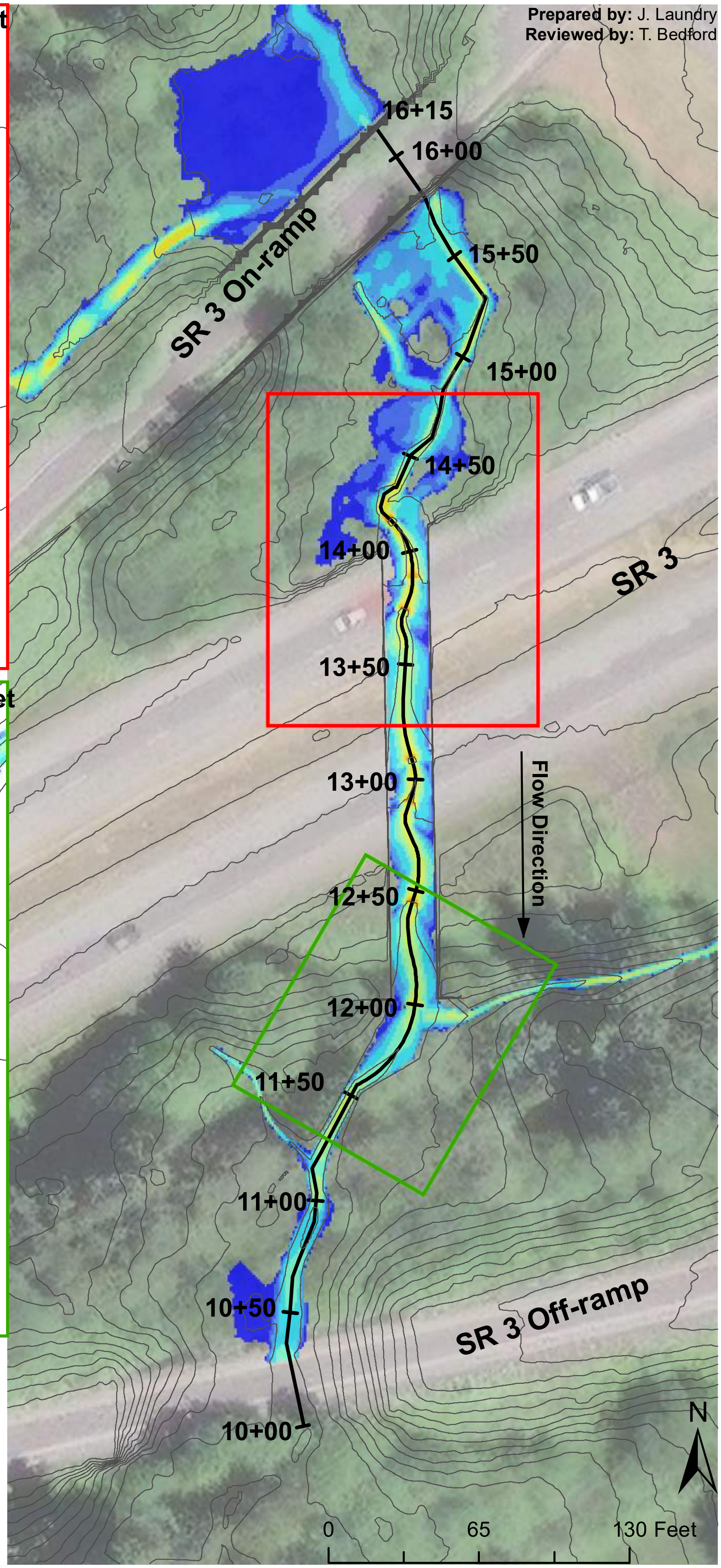
*Alignment shown cooresponds to alignment on Sheet CR1 in Appendix D

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







Proposed Conditions, 2yr Velocity

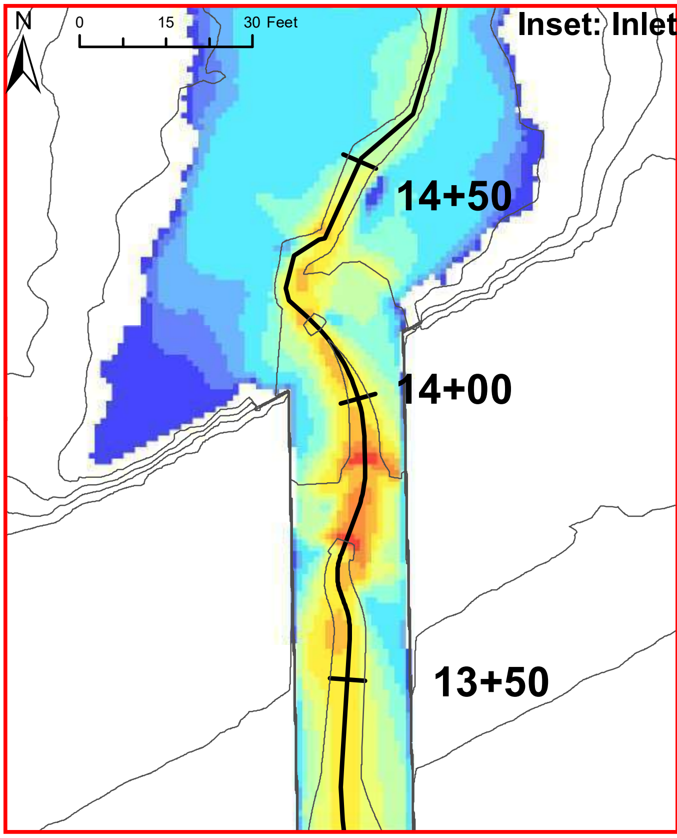
Velocity (fps)

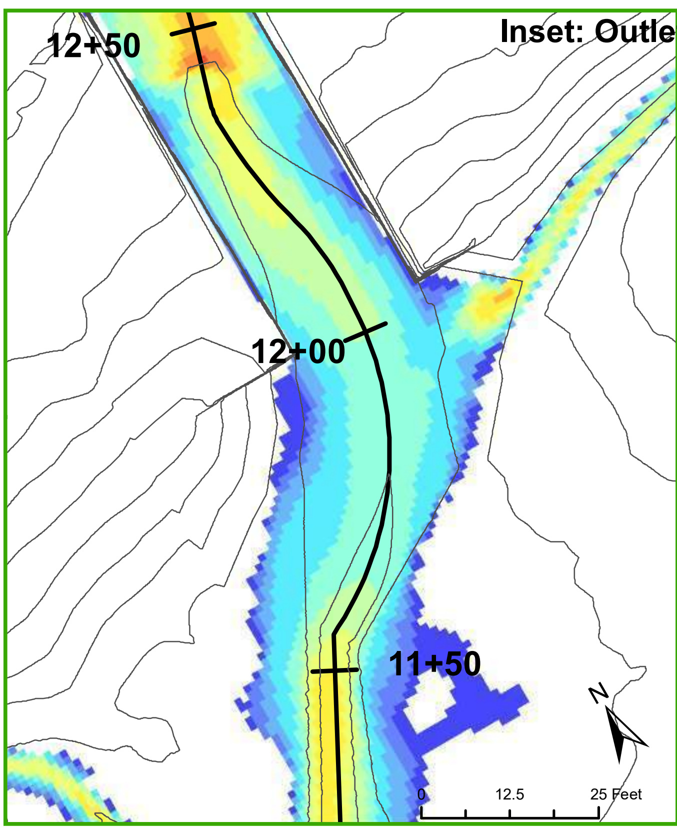
< 0.25	2.0 - 3	6.0 - 7
0.25 - 0.5	3.01 - 4	7.0 - 8
0.5 - 1	4.0 - 5	8.0 - 9
1.0 - 2	5.0 - 6	

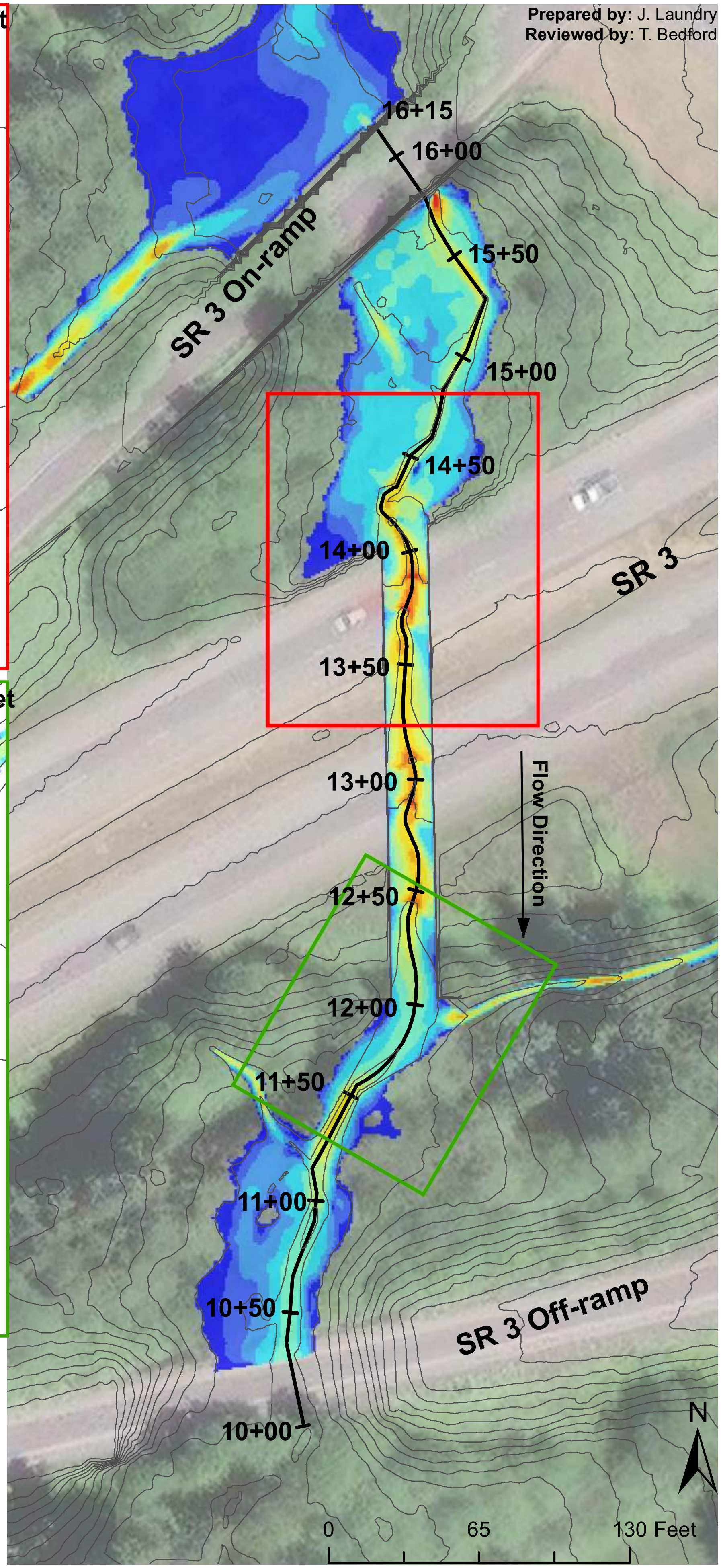
*Alignment shown cooresponds to alignment on Sheet CR1 in Appendix D

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







Propoced Conditions, 100yr Velocity

Velocity (fps)

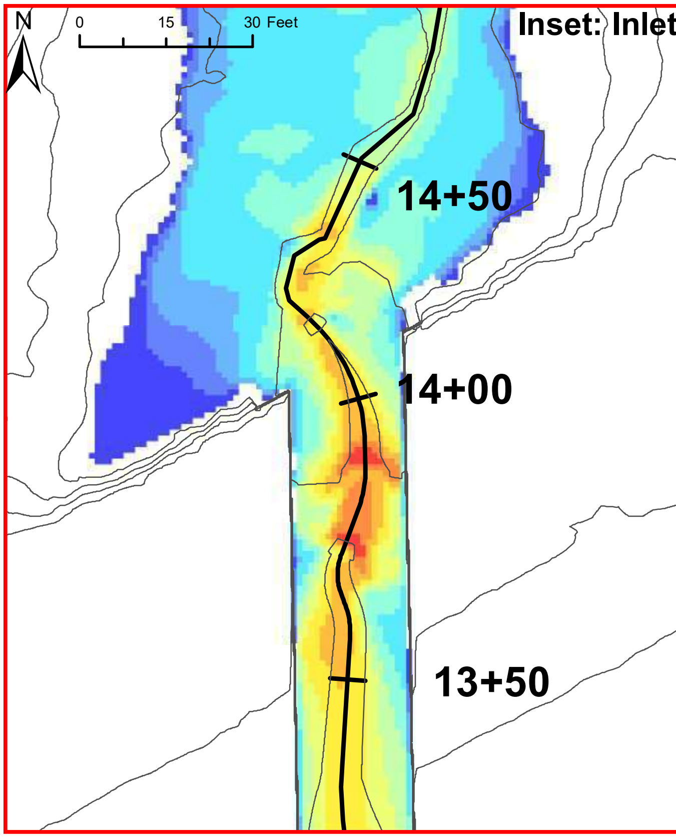
- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 2
- 2.0 - 3
- 3.01 - 4
- 4.0 - 5
- 5.0 - 6
- 6.0 - 7
- 7.0 - 8
- 8.0 - 9

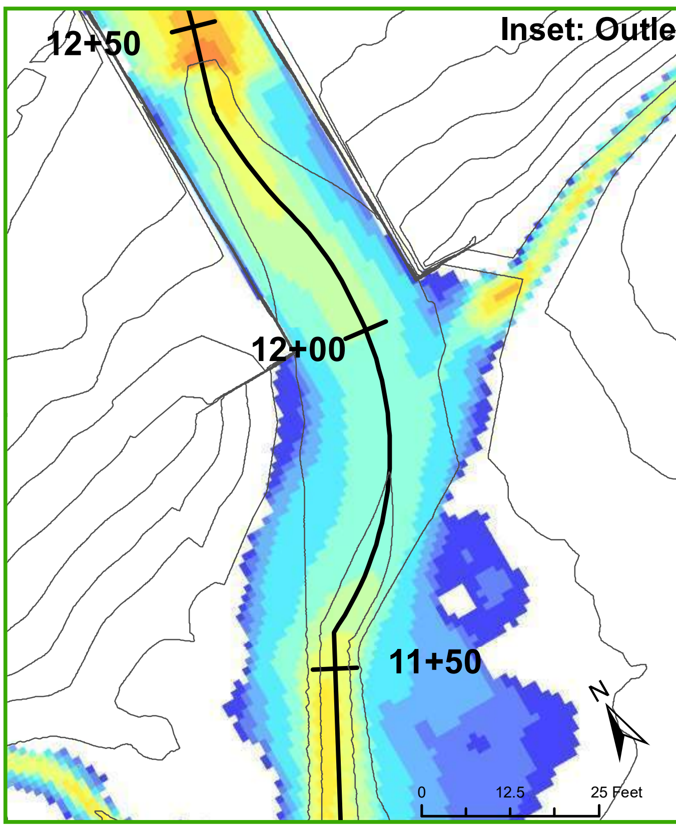
*Alignment shown cooresponds to alignment on Sheet CR1 in Appendix D

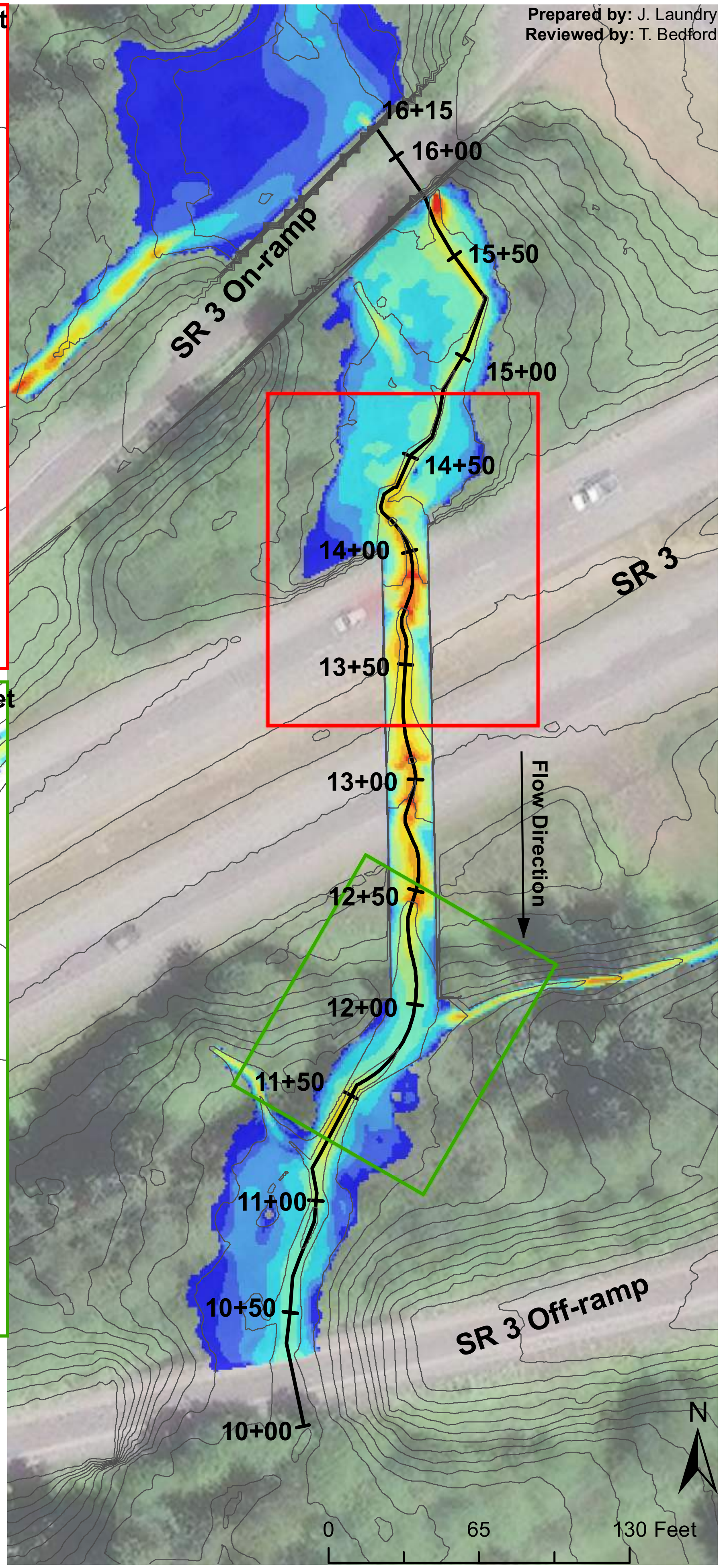
WSDOT OLYMPIC REGION GEC

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







Propoced Conditions, 500yr Velocity

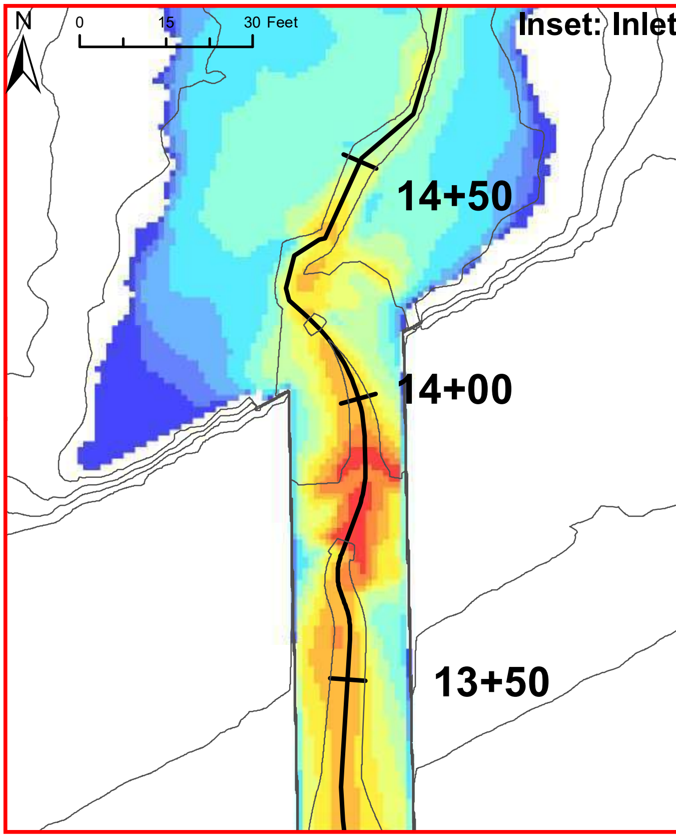
Velocity (fps)

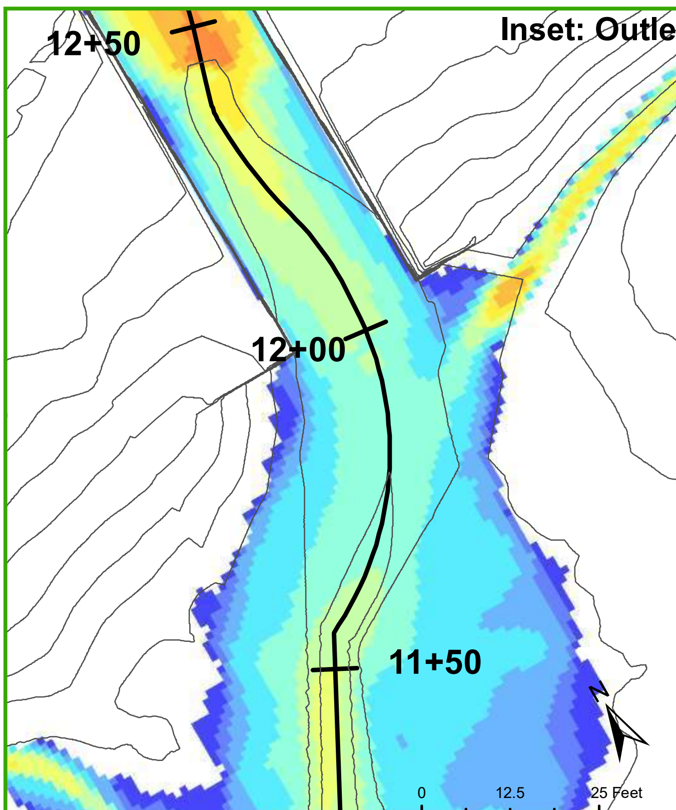
- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 2
- 2.0 - 3
- 3.01 - 4
- 4.0 - 5
- 5.0 - 6
- 6.0 - 7
- 7.0 - 8
- 8.0 - 9

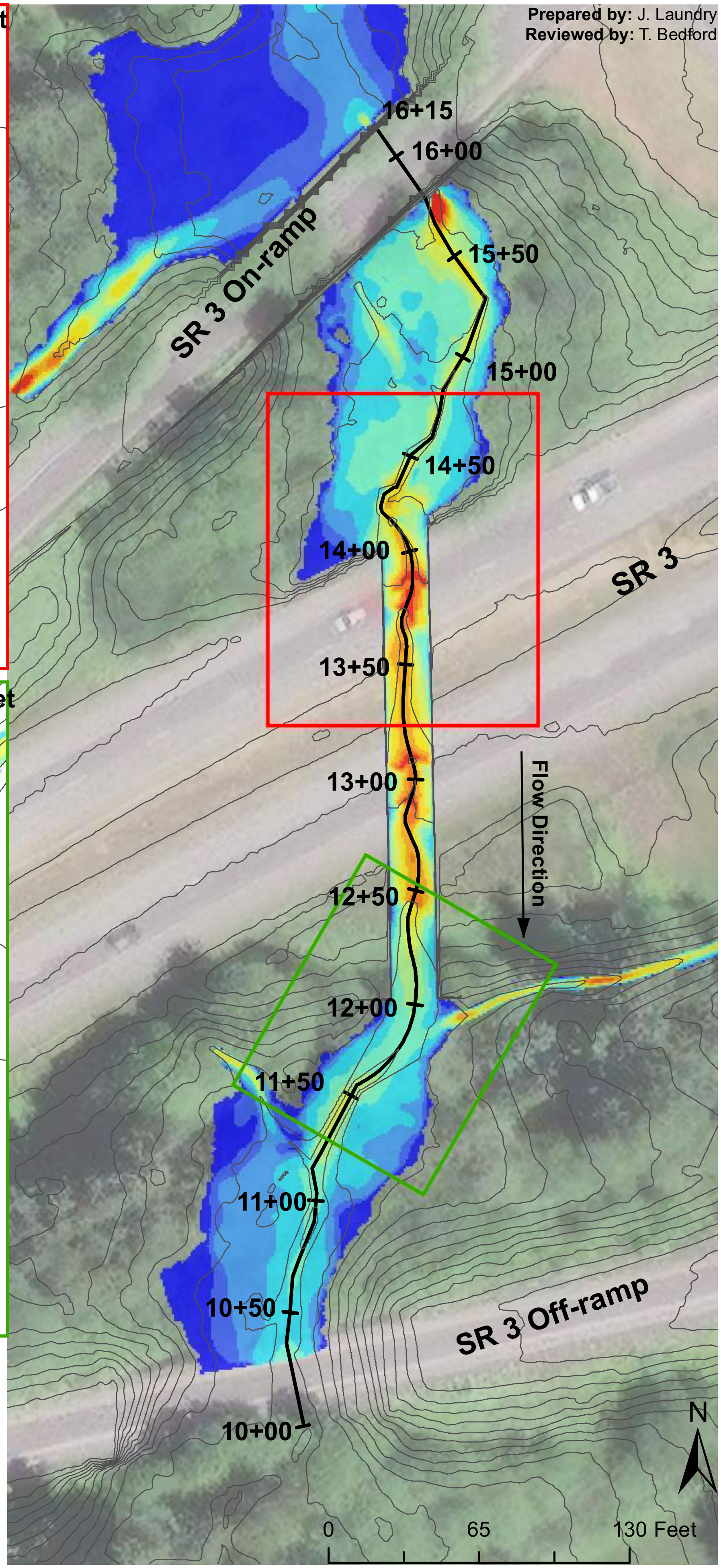
*Alignment shown coorespond to alignment on Sheet CR1 in Appendix D

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







Proposed Conditions, Projected 2080 100yr Velocity

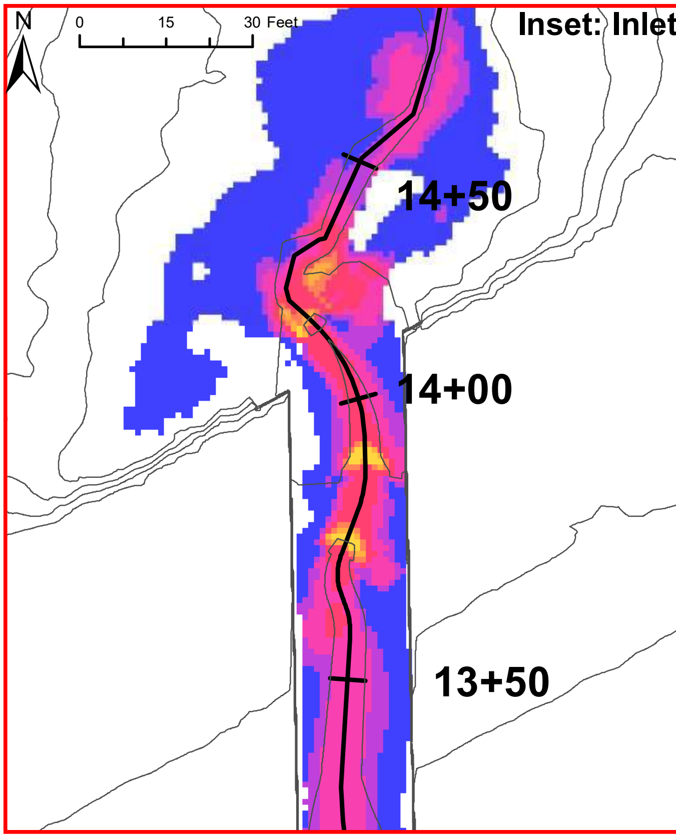
Velocity (fps)

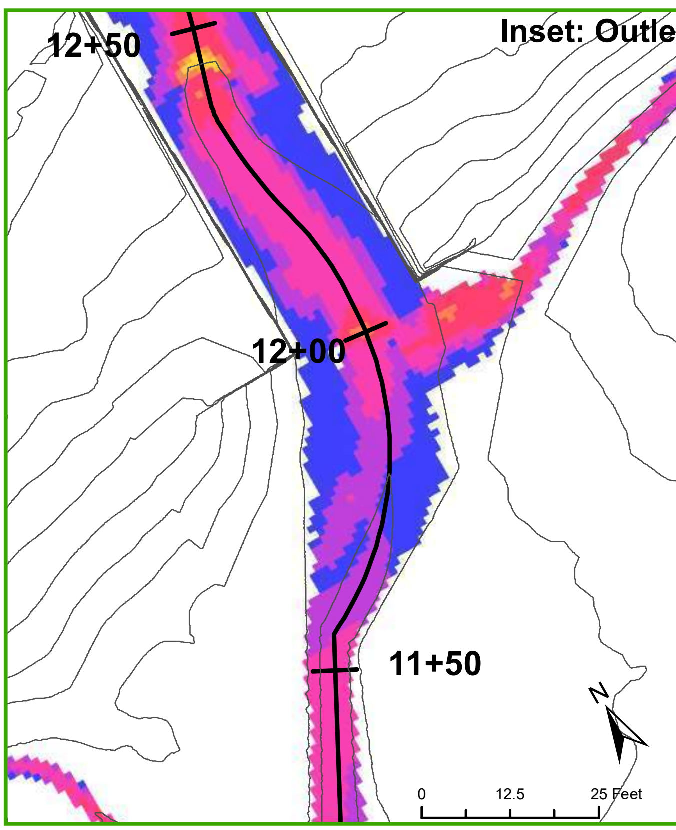
- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 2
- 2.0 - 3
- 3.01 - 4
- 4.0 - 5
- 5.0 - 6
- 6.0 - 7
- 7.0 - 8
- 8.0 - 9

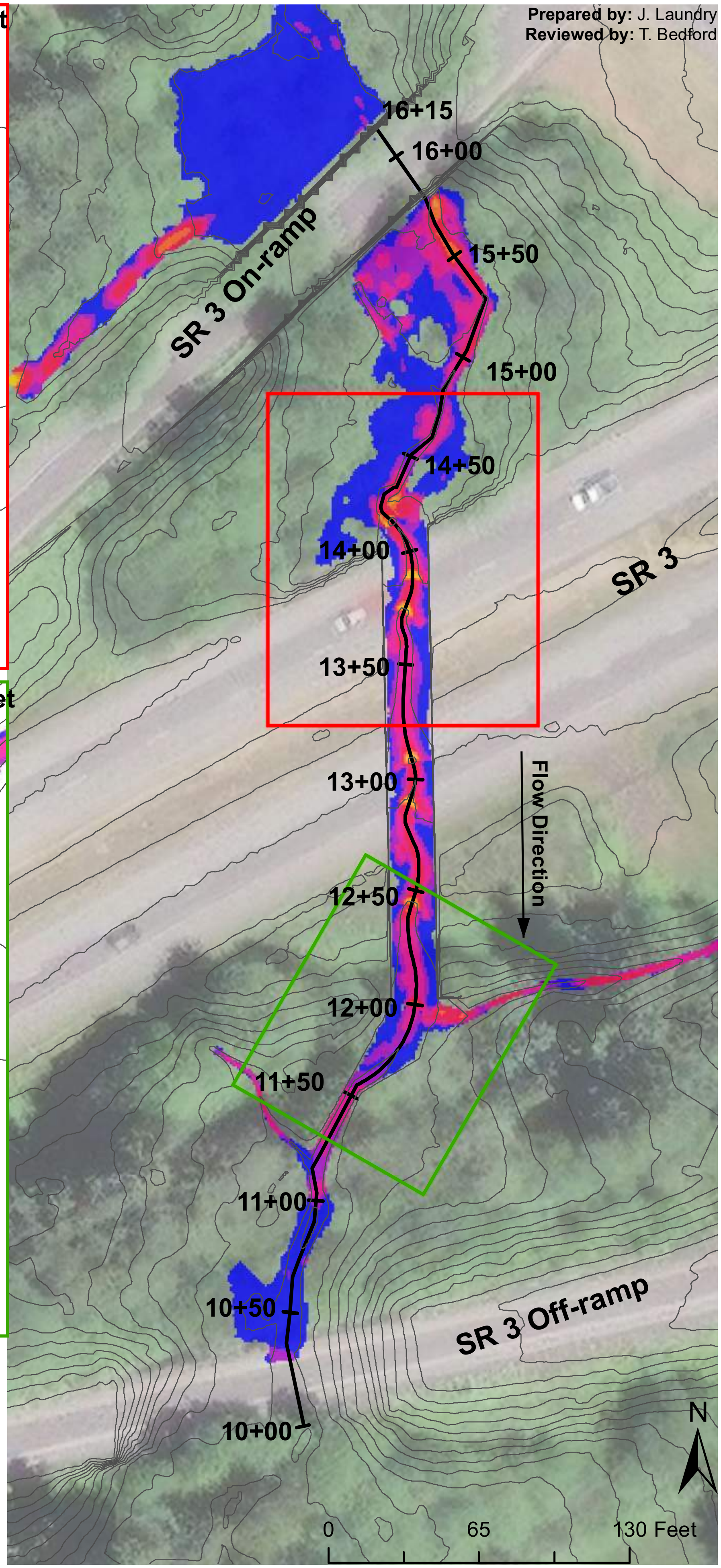
*Alignment shown coorespondes to alignment on Sheet CR1 in Appendix D

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







Proposed Conditions, 2yr Shear Stress

Shear Stress (psf)

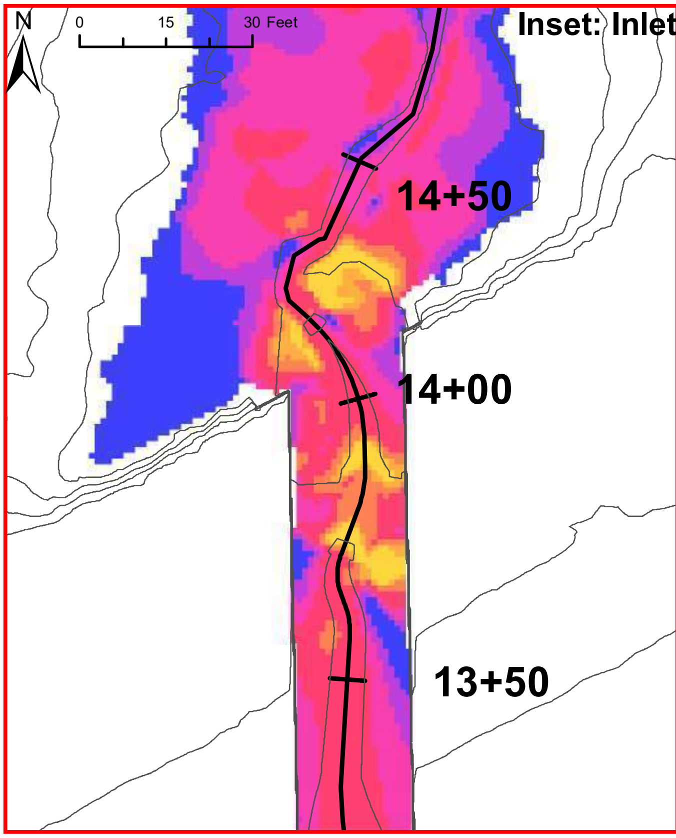
- 0 - 0.1
- 0.10 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- > 4

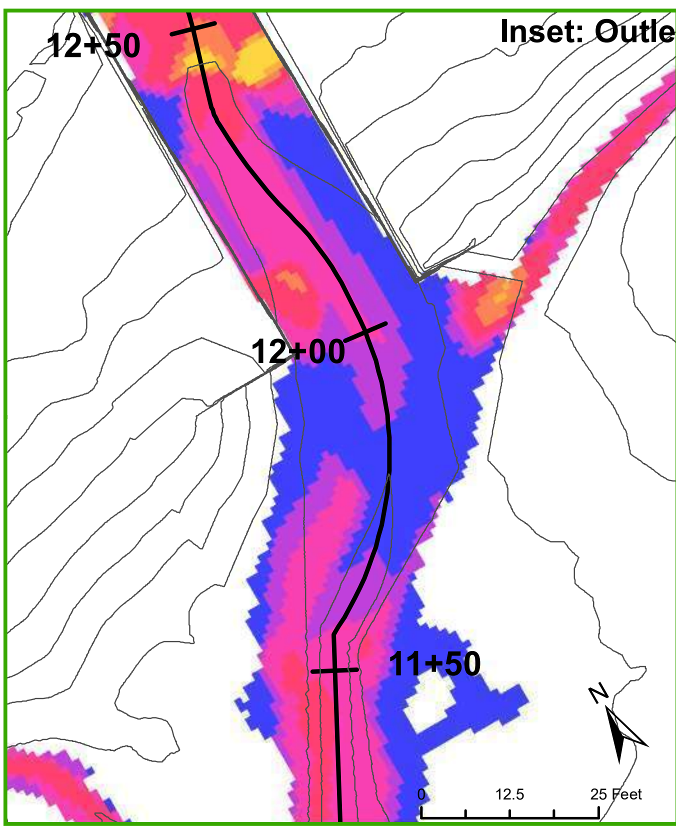
*Alignment shown cooresponds to alignment on Sheet CR1 in Appendix D

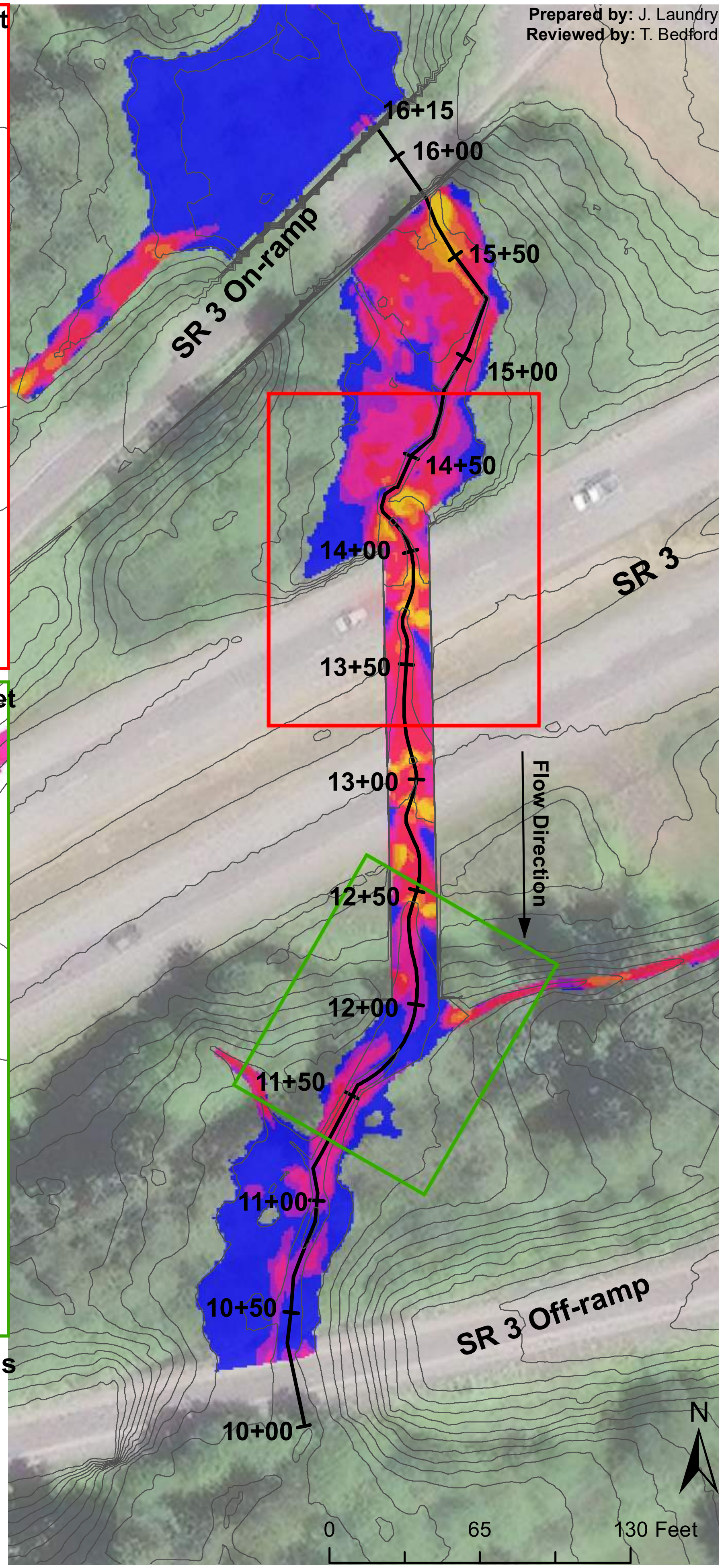
WSDOT OLYMPIC REGION GEC

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs







Proposed Conditions, 100yr Shear Stress

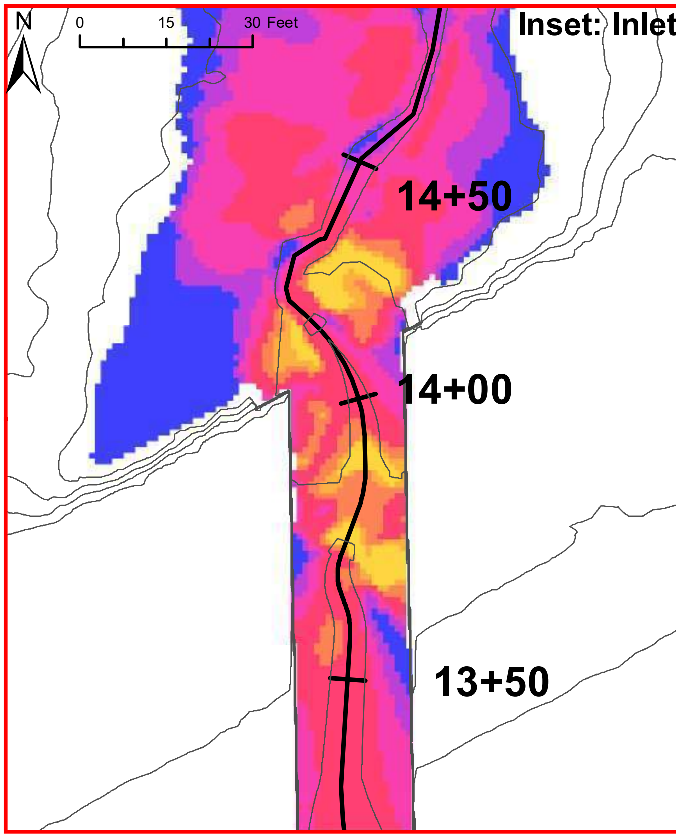
Shear Stress (psf)

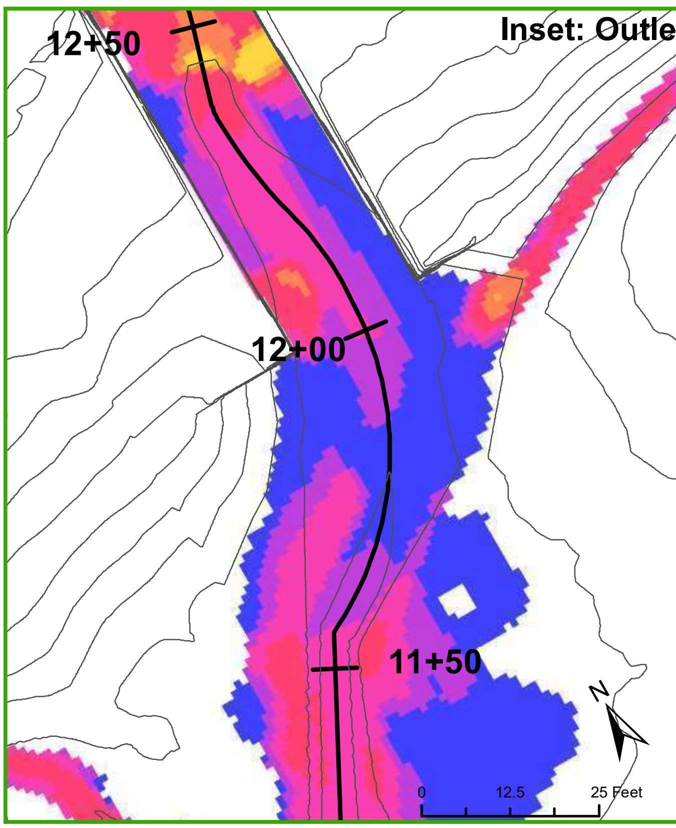
- 0 - 0.1
- 0.10 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- > 4

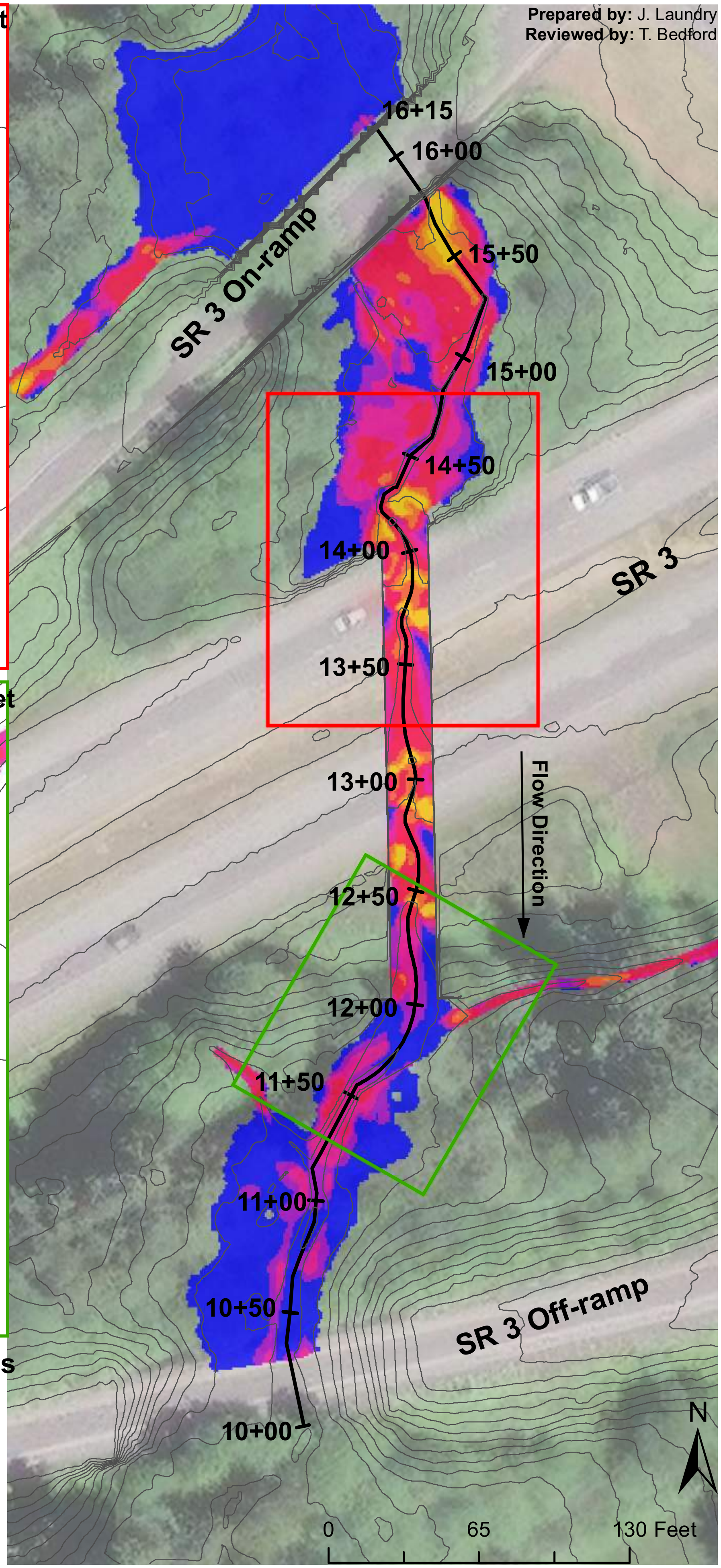
*Alignment shown cooresponds to alignment on Sheet CR1 in Appendix D

Appendix H

SR 3 MP 52.21 Johnson Creek to Liberty Bay - Model Outputs





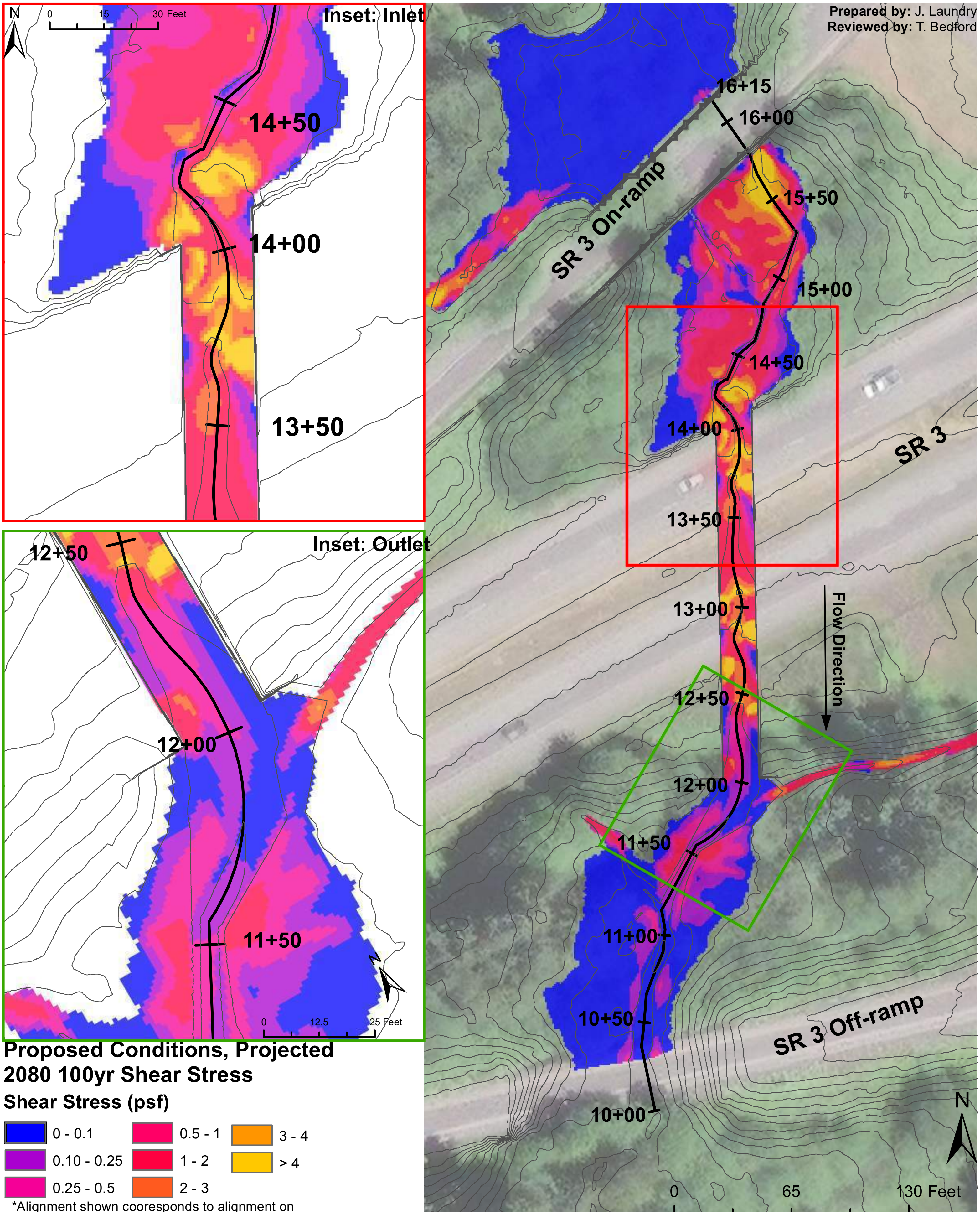


Proposed Conditions, 500yr Shear Stress

Shear Stress (psf)

0 - 0.1	0.5 - 1	3 - 4
0.10 - 0.25	1 - 2	> 4
0.25 - 0.5	2 - 3	

*Alignment shown cooresponds to alignment on Sheet CR1 in Appendix D

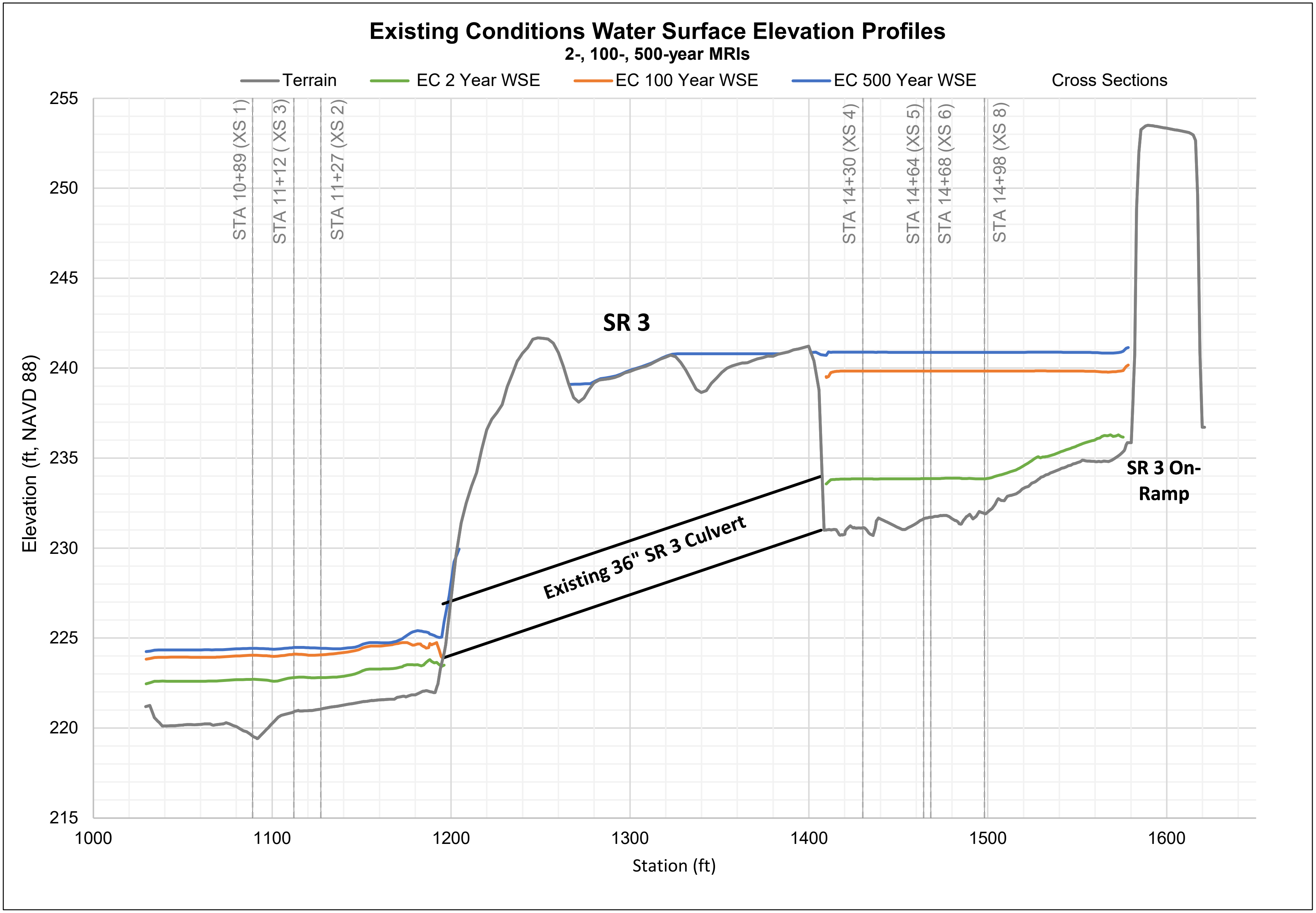


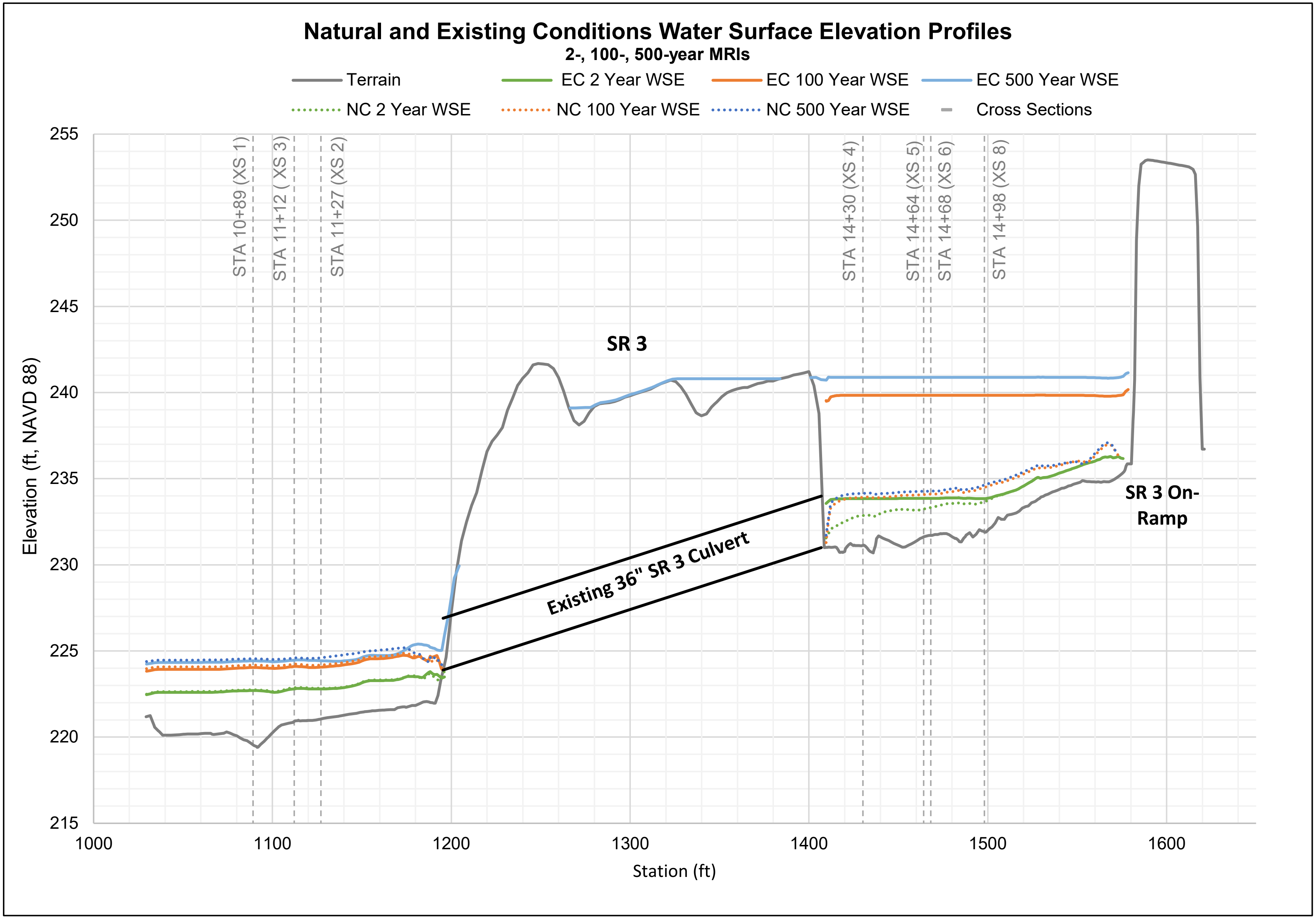
Proposed Conditions, Projected 2080 100yr Shear Stress

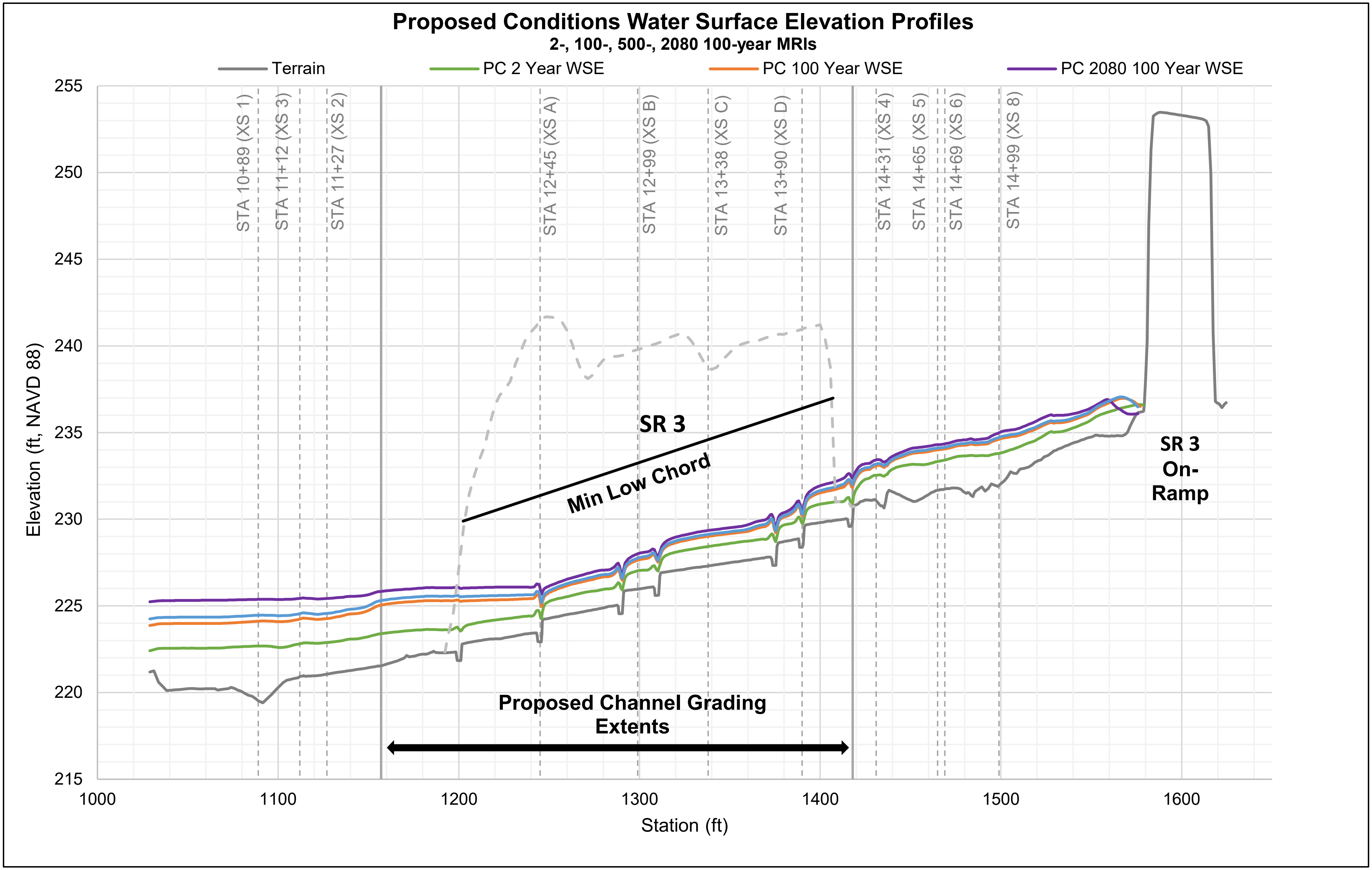
Shear Stress (psf)

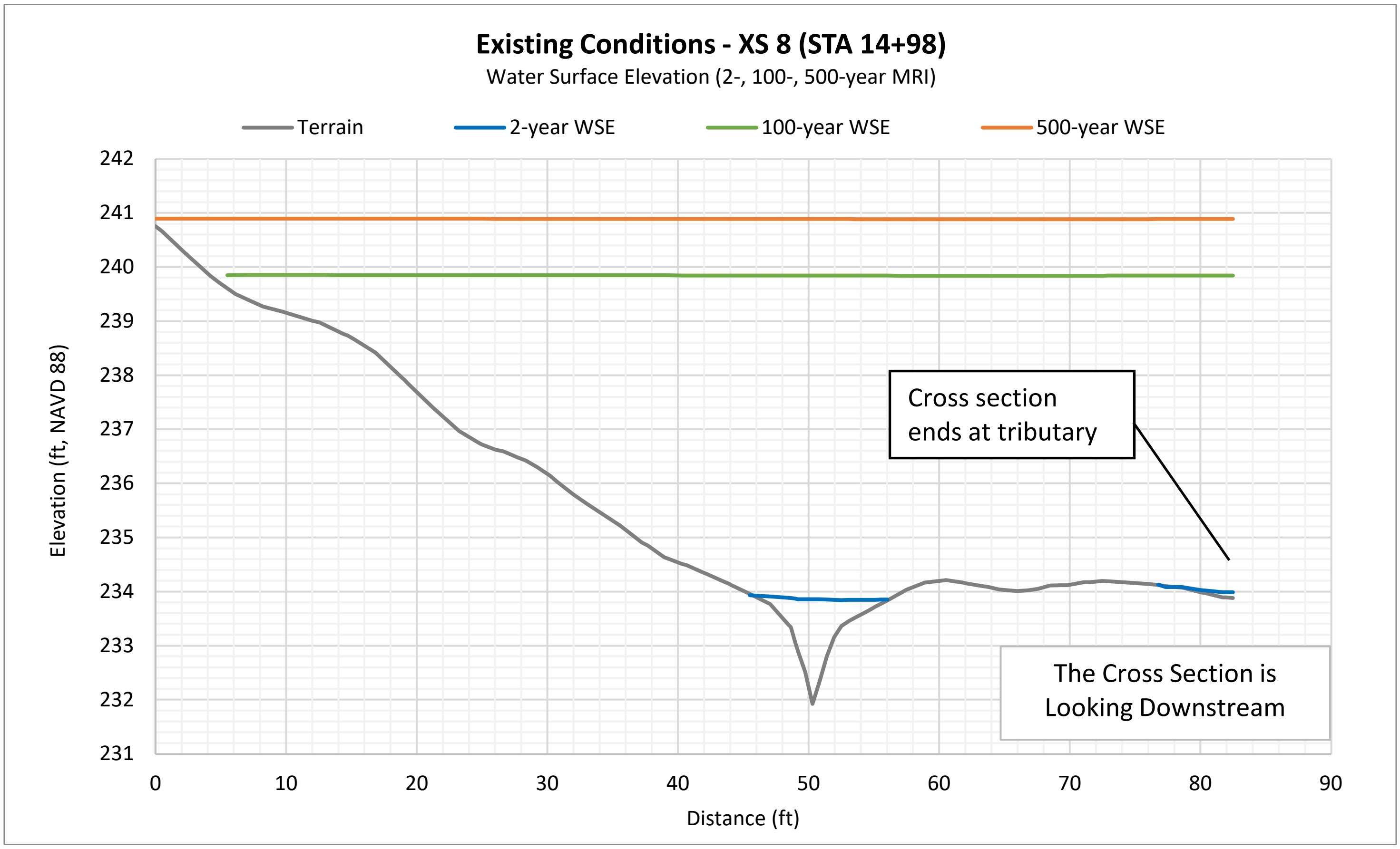
0 - 0.1
0.10 - 0.25
0.25 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 4
> 4

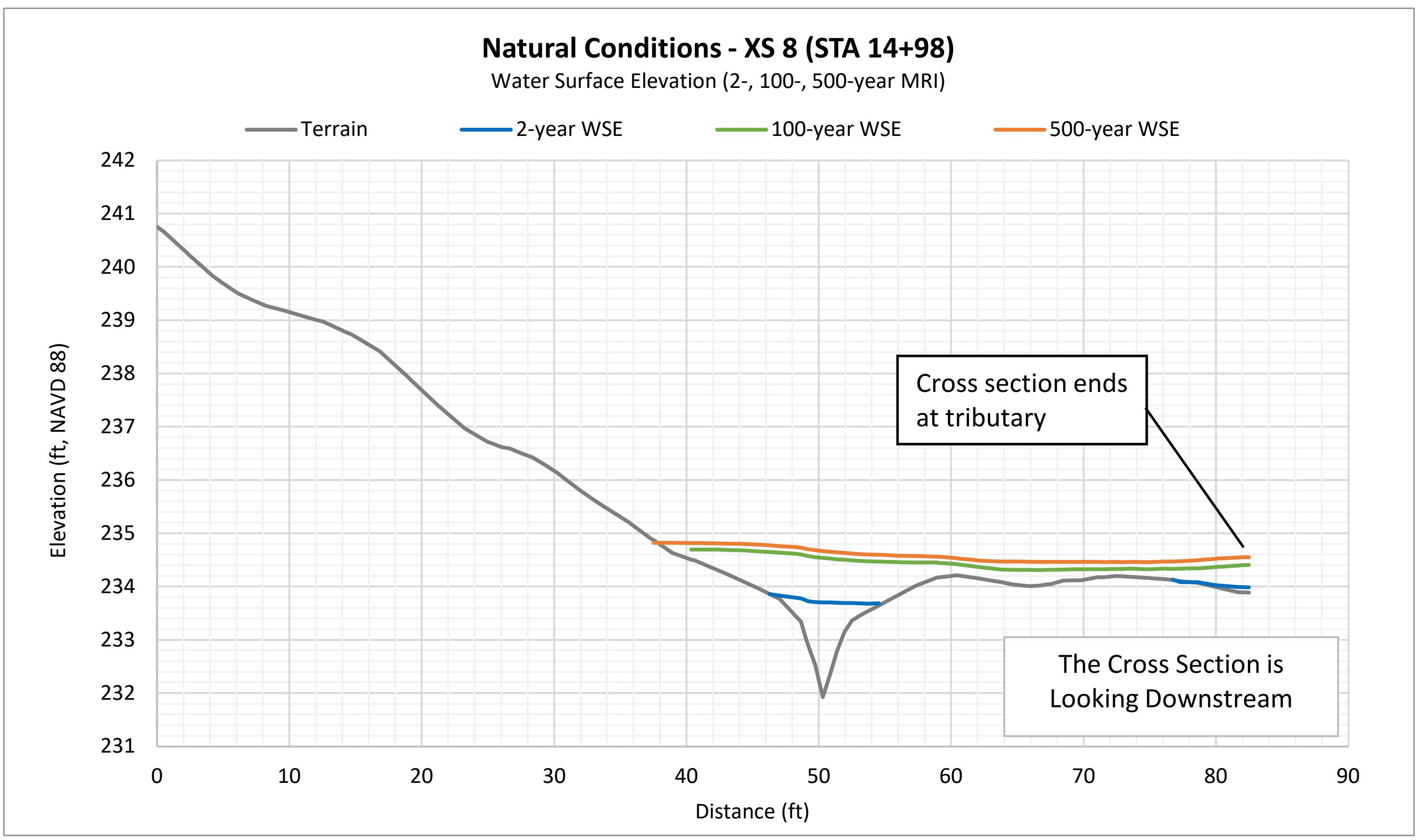
*Alignment shown cooresponds to alignment on Sheet CR1 in Appendix D

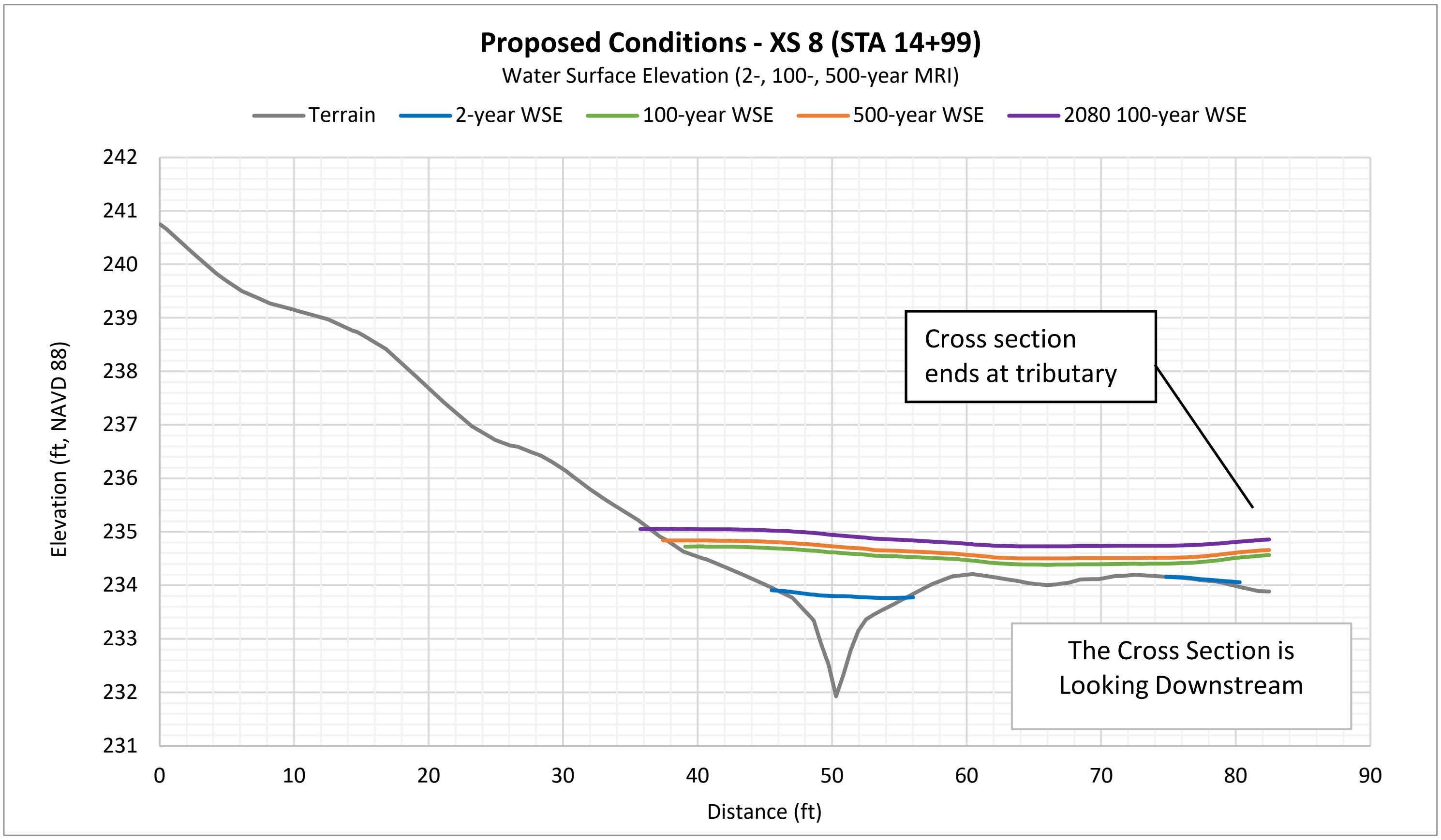

Existing Conditions Water Surface Elevation Profiles
2-, 100-, 500-year MRIs
Terrain
EC 2 Year WSE
EC 100 Year WSE
EC 500 Year WSE
Cross Sections
STA 10+89 (XS 1)
STA 11+12 (XS 3)
STA 11+27 (XS 2)
STA 14+30 (XS 4)
STA 14+64 (XS 5)
STA 14+68 (XS 6)
STA 14+98 (XS 8)
SR 3
Existing 36" SR 3 Culvert
SR 3 On-Ramp
Elevation (ft, NAVD 88)
Station (ft)
255
250
245
240
235
230
225
220
215
1000
1100
1200
1300
1400
1500
1600

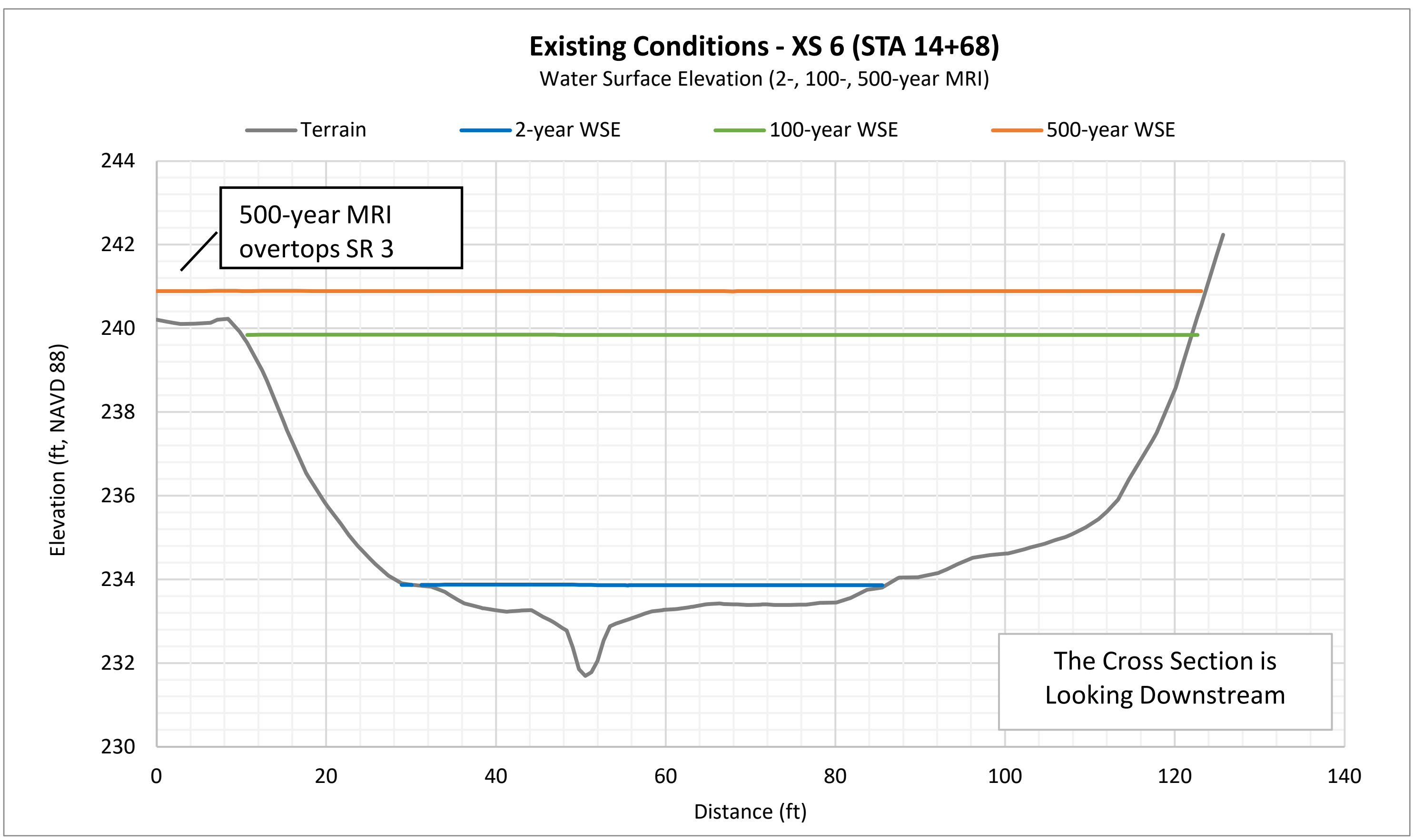

Natural and Existing Conditions Water Surface Elevation Profiles
2-, 100-, 500-year MRIs
Terrain
EC 2 Year WSE
EC 100 Year WSE
EC 500 Year WSE
NC 2 Year WSE
NC 100 Year WSE
NC 500 Year WSE
Cross Sections
Elevation (ft, NAVD 88)
Station (ft)
STA 10+89 (XS 1)
STA 11+12 (XS 3)
STA 11+27 (XS 2)
STA 14+30 (XS 4)
STA 14+64 (XS 5)
STA 14+68 (XS 6)
STA 14+98 (XS 8)
SR 3
Existing 36" SR 3 Culvert
SR 3 On-Ramp
255
250
245
240
235
230
225
220
215
1000
1100
1200
1300
1400
1500
1600

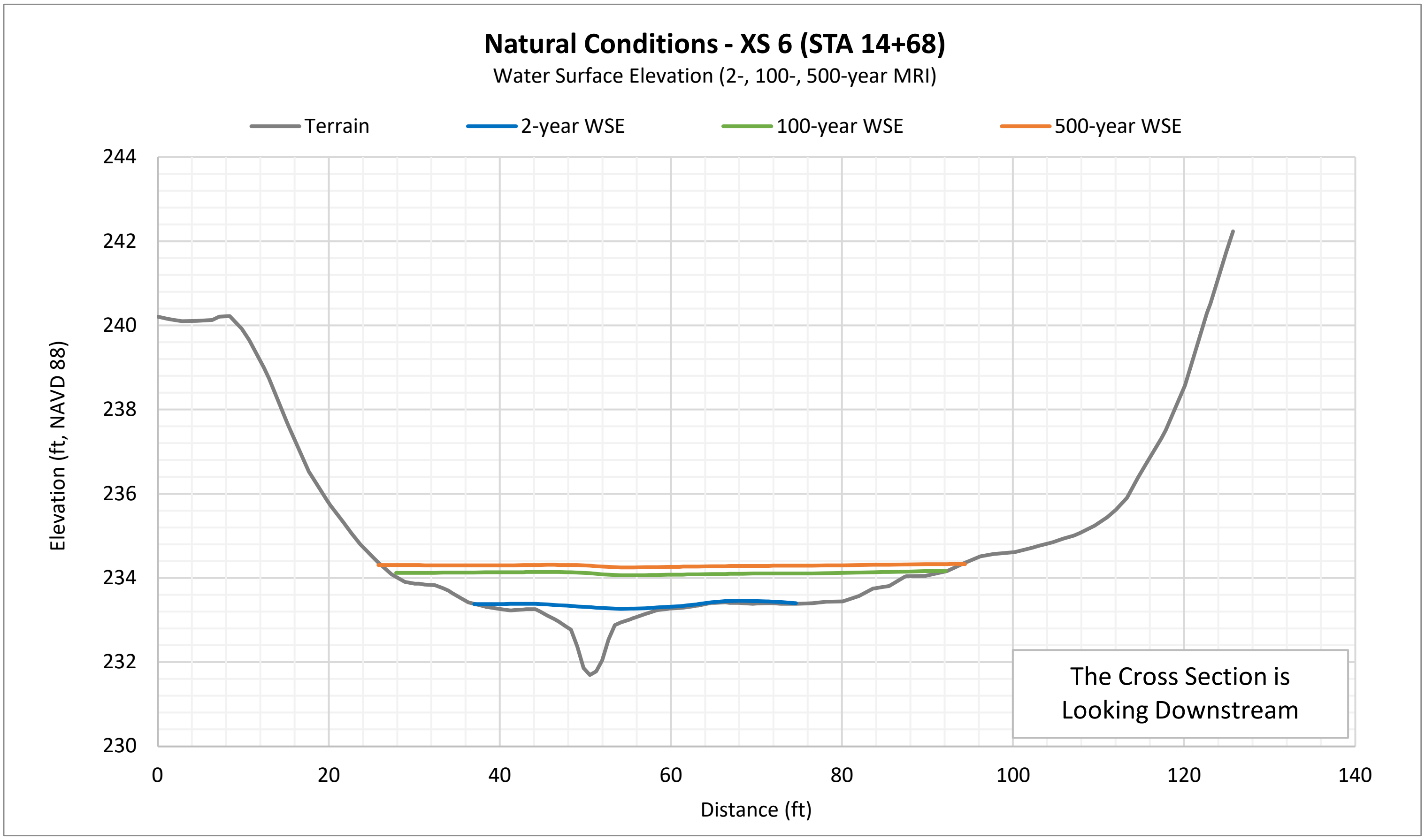

Proposed Conditions Water Surface Elevation Profiles
2-, 100-, 500-, 2080 100-year MRIs
Terrain
PC 2 Year WSE
PC 100 Year WSE
PC 2080 100 Year WSE
Elevation (ft, NAVD 88)
Station (ft)
255
250
245
240
235
230
225
220
215
1000
1100
1200
1300
1400
1500
1600
STA 10+89 (XS 1)
STA 11+12 (XS 3)
STA 11+27 (XS 2)
STA 12+45 (XS A)
STA 12+99 (XS B)
STA 13+38 (XS C)
STA 13+90 (XS D)
STA 14+31 (XS 4)
STA 14+65 (XS 5)
STA 14+69 (XS 6)
STA 14+99 (XS 8)
SR 3
Min Low Chord
SR 3 On-Ramp
Proposed Channel Grading Extents

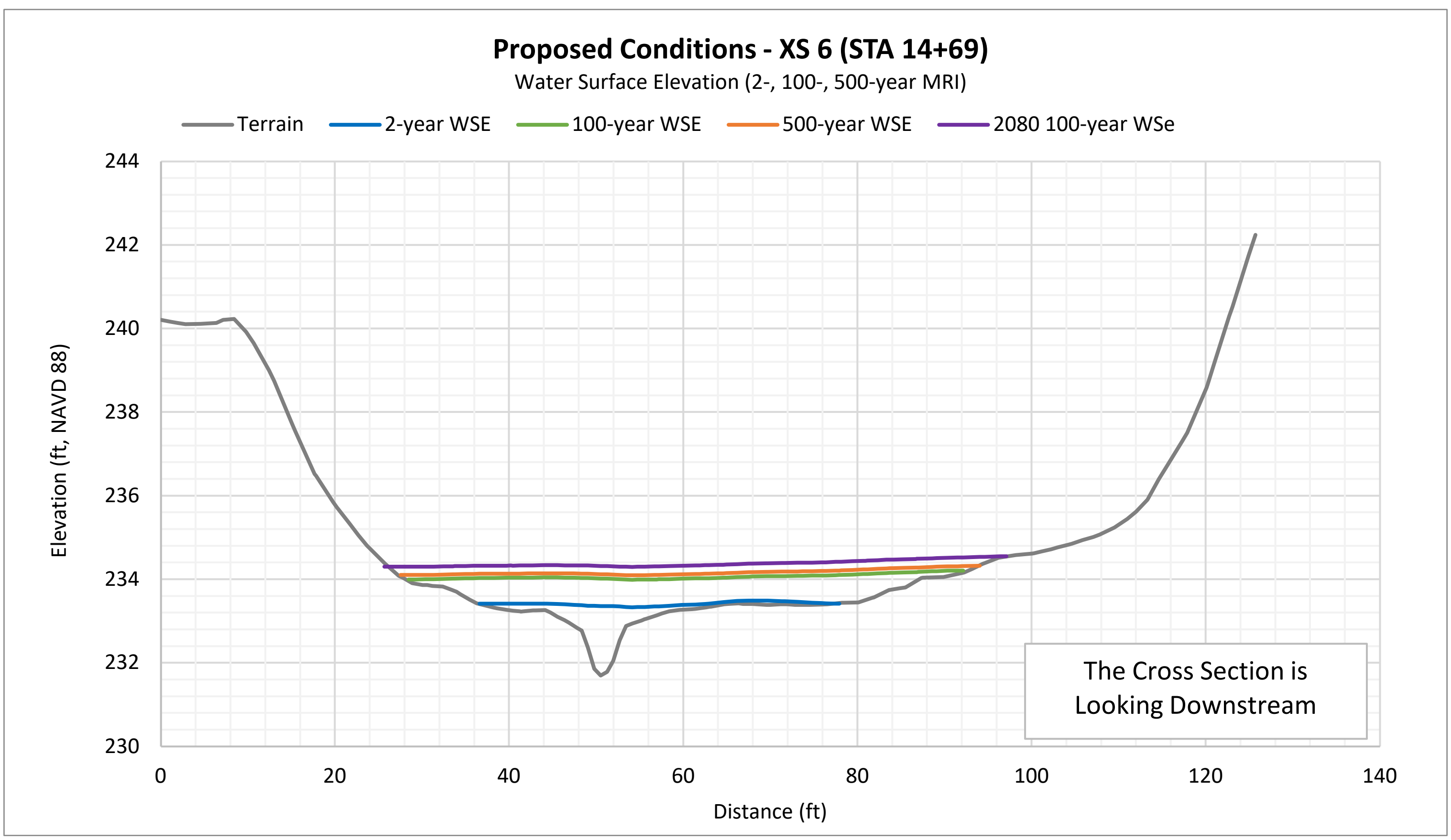

Existing Conditions - XS 8 (STA 14+98)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
Elevation (ft, NAVD 88)
Distance (ft)
Cross section ends at tributary
The Cross Section is Looking Downstream

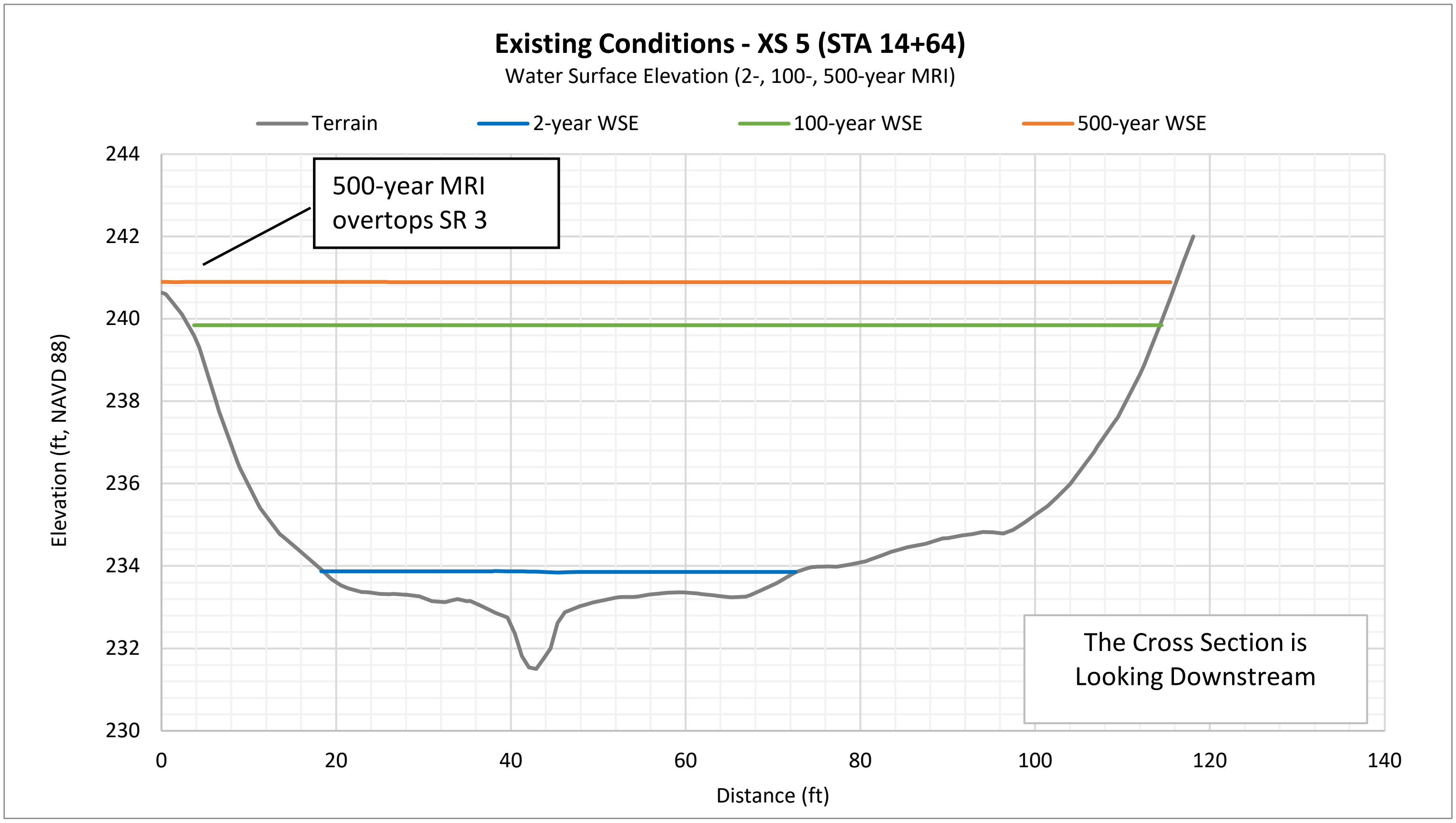

Natural Conditions - XS 8 (STA 14+98)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
Elevation (ft, NAVD 88)
Distance (ft)
Cross section ends at tributary
The Cross Section is Looking Downstream

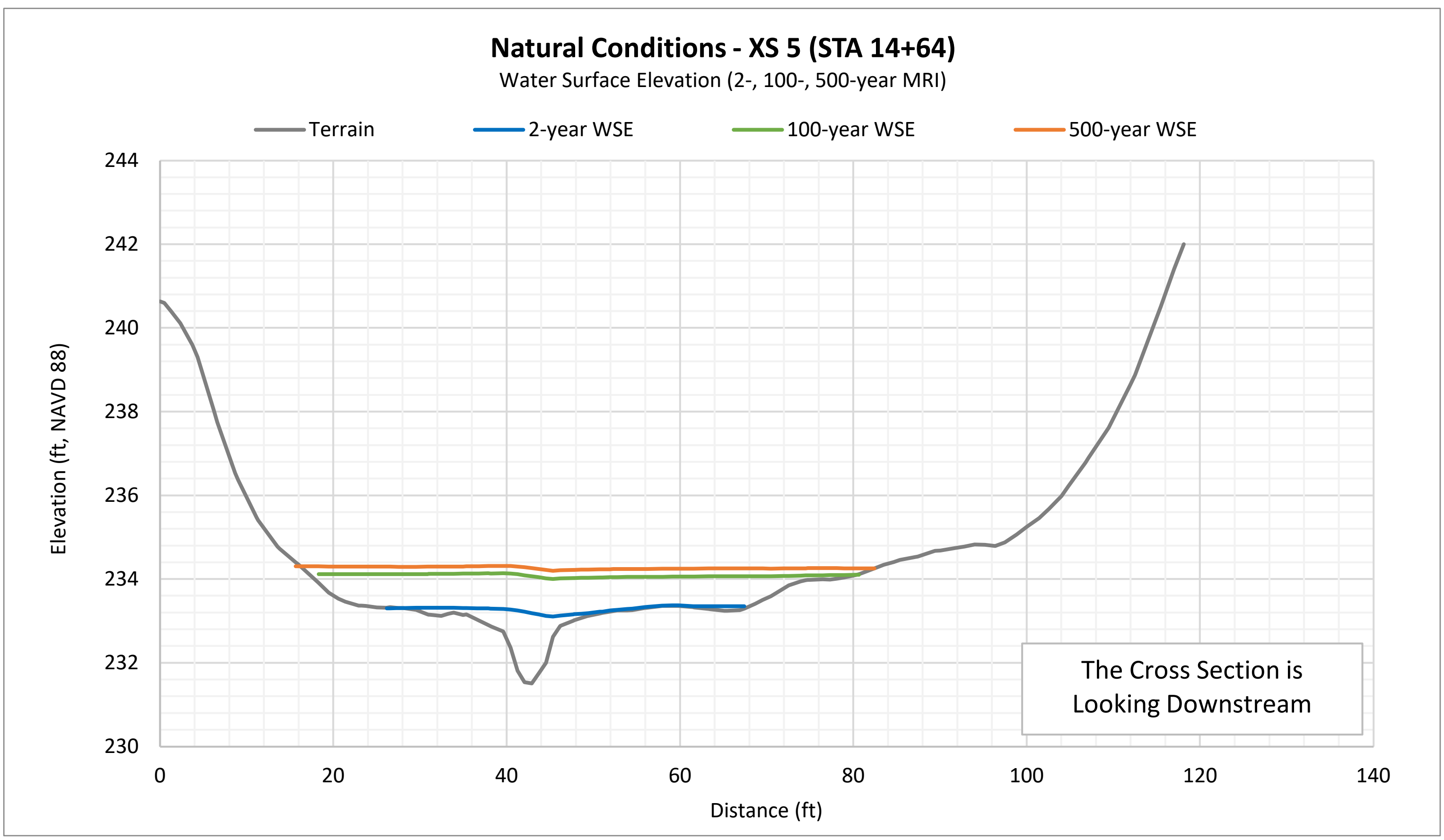

Proposed Conditions - XS 8 (STA 14+99)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
2080 100-year WSE
Elevation (ft, NAVD 88)
Distance (ft)
Cross section ends at tributary
The Cross Section is Looking Downstream

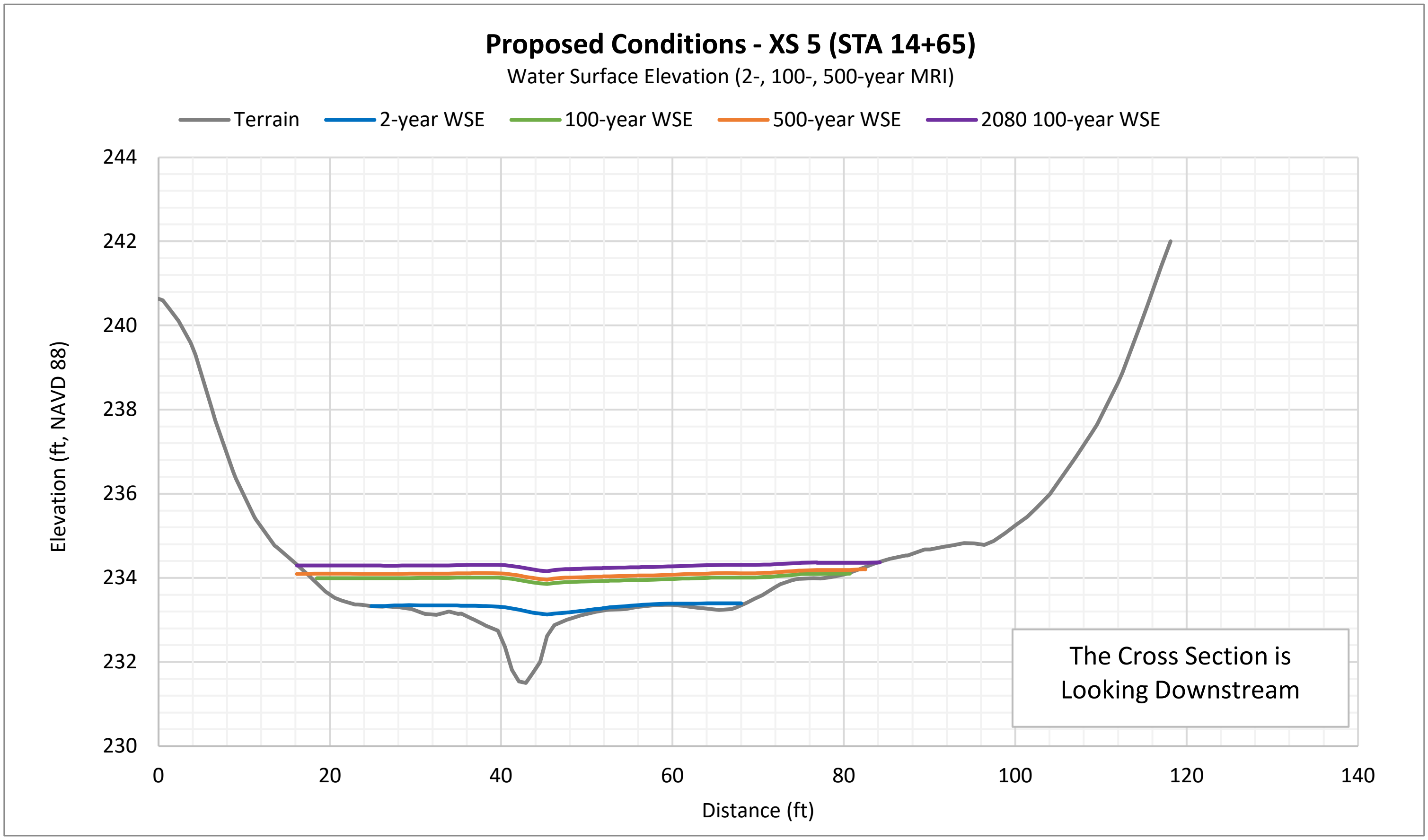

Existing Conditions - XS 6 (STA 14+68)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
Elevation (ft, NAVD 88)
Distance (ft)
500-year MRI overtops SR 3
The Cross Section is Looking Downstream

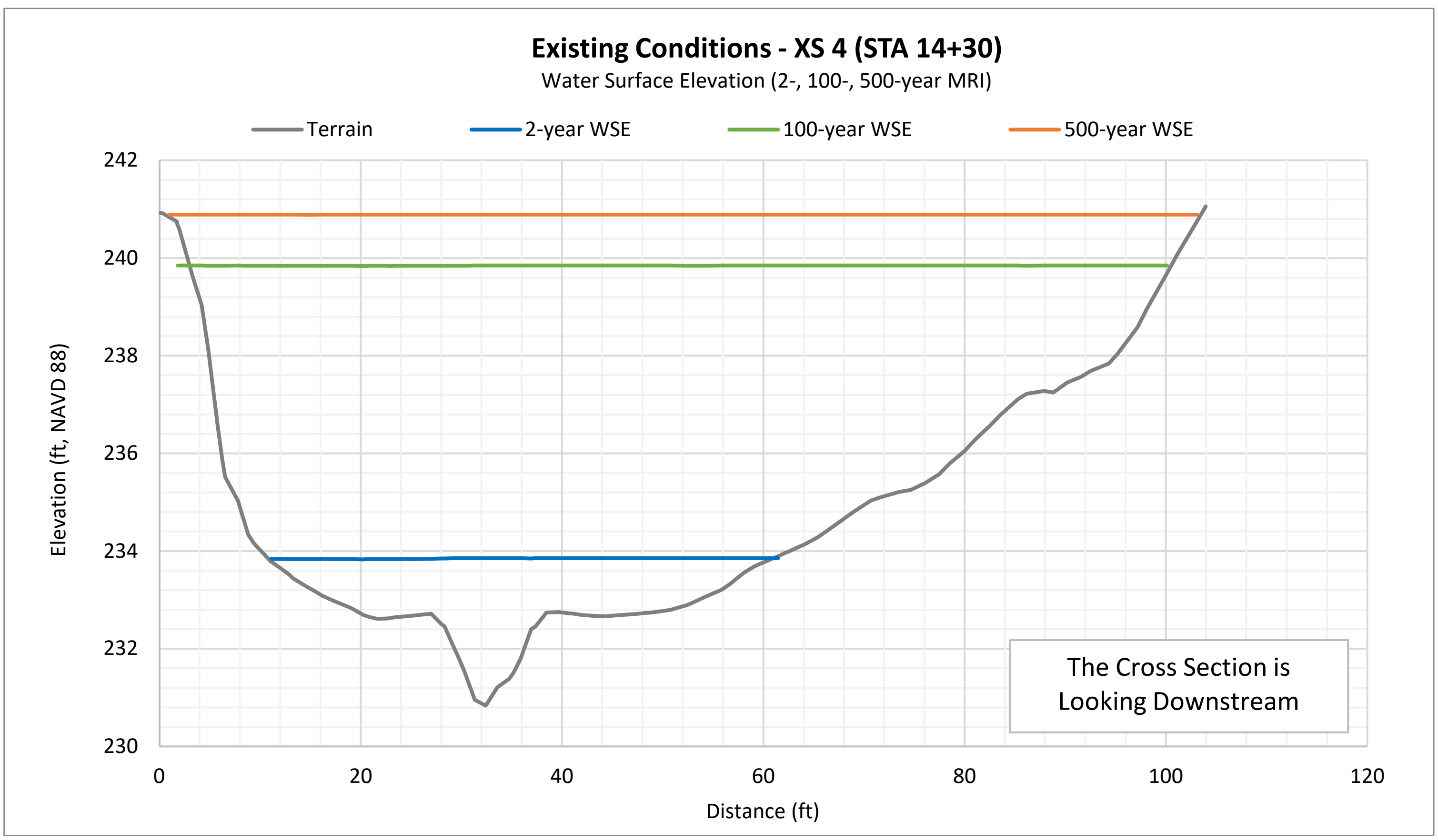

Natural Conditions - XS 6 (STA 14+68)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
Elevation (ft, NAVD 88)
244
242
240
238
236
234
232
230
0
20
40
60
80
100
120
140
Distance (ft)
The Cross Section is Looking Downstream

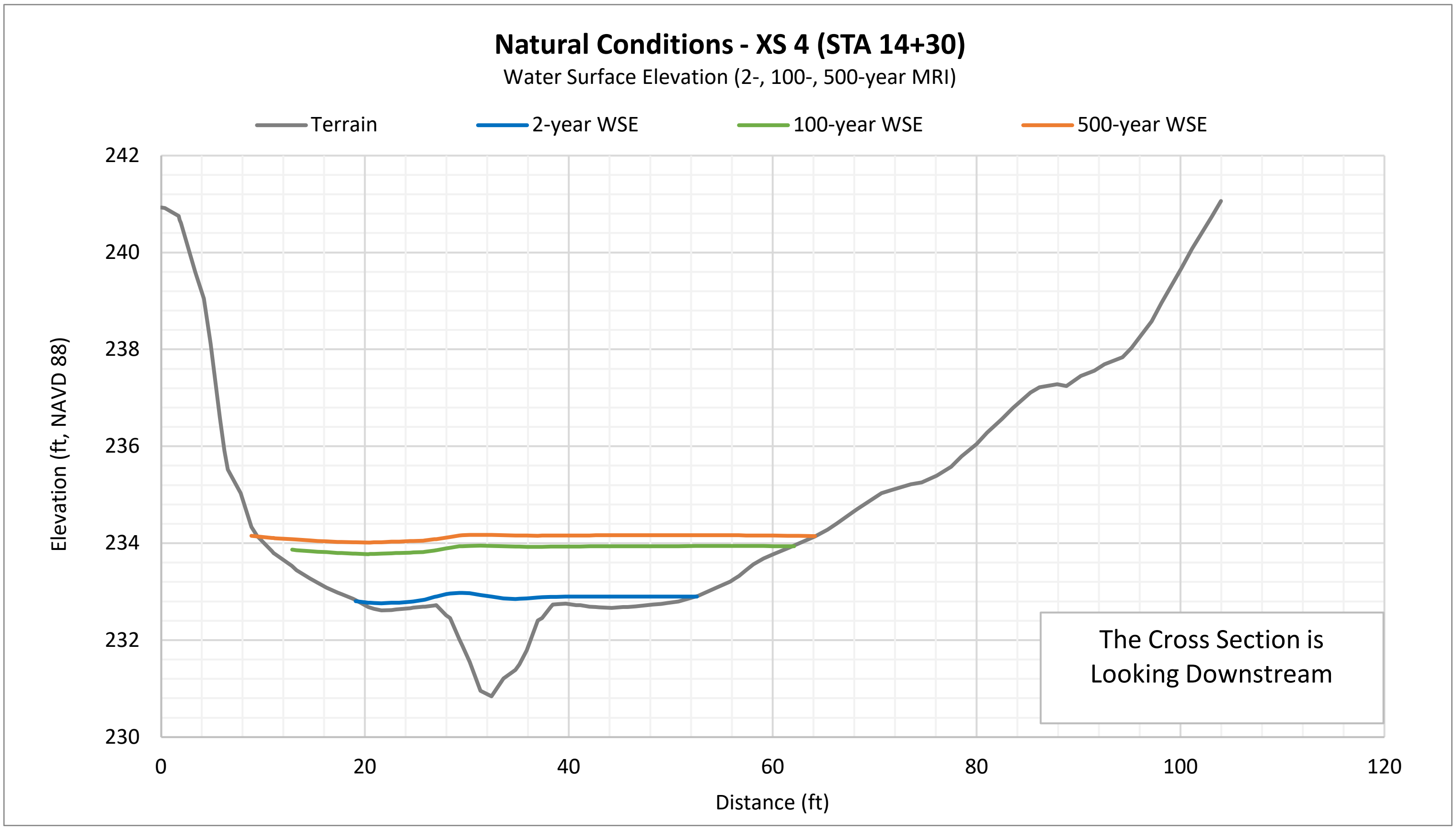

Proposed Conditions - XS 6 (STA 14+69)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
2080 100-year WSe
Elevation (ft, NAVD 88)
244
242
240
238
236
234
232
230
0
20
40
60
80
100
120
140
Distance (ft)
The Cross Section is Looking Downstream

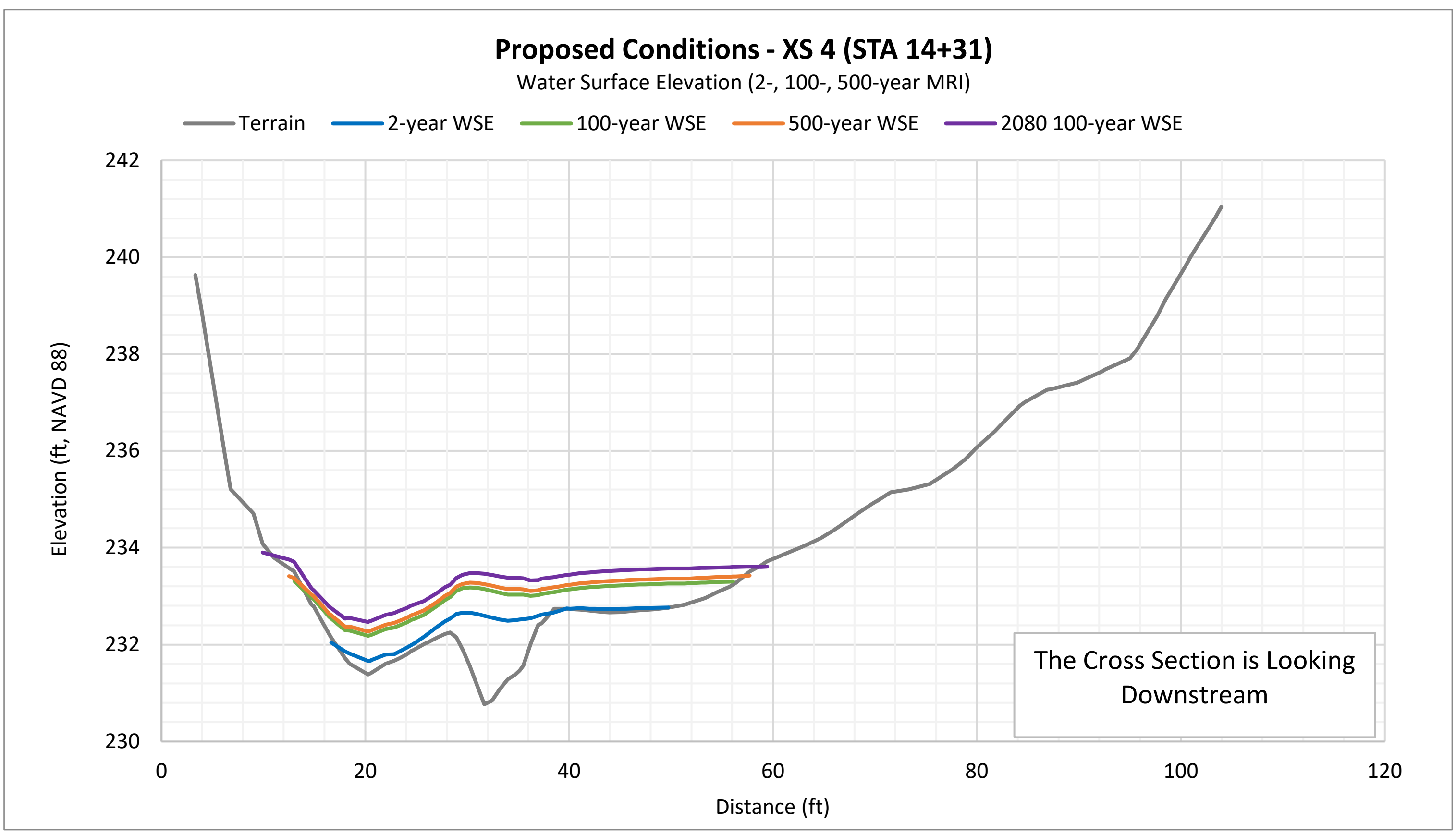

Existing Conditions - XS 5 (STA 14+64)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
500-year MRI overtops SR 3
The Cross Section is Looking Downstream
Elevation (ft, NAVD 88)
Distance (ft)
244
242
240
238
236
234
232
230
0
20
40
60
80
100
120
140

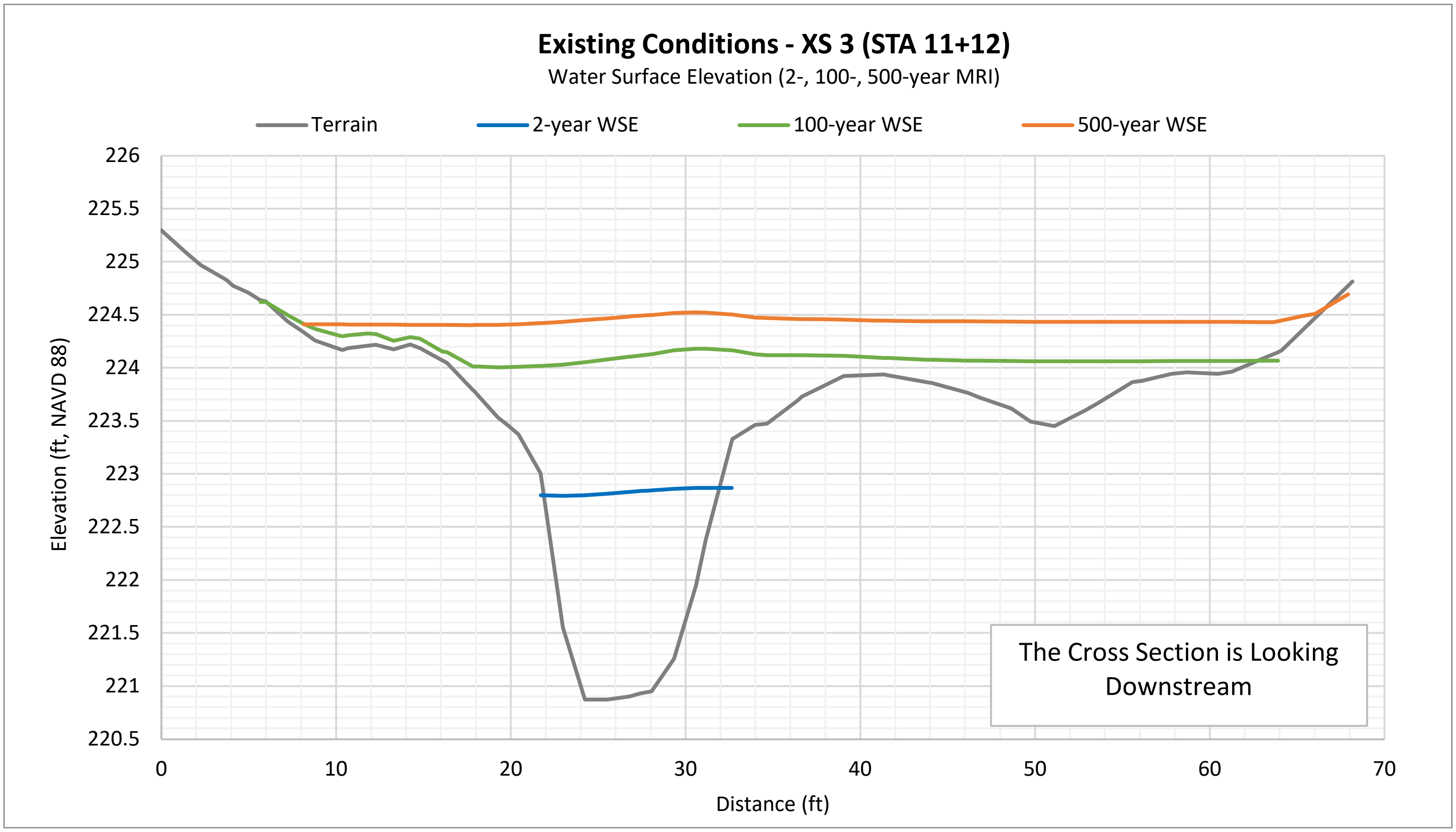

Natural Conditions - XS 5 (STA 14+64)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
The Cross Section is Looking Downstream
Elevation (ft, NAVD 88)
Distance (ft)
244
242
240
238
236
234
232
230
0
20
40
60
80
100
120
140

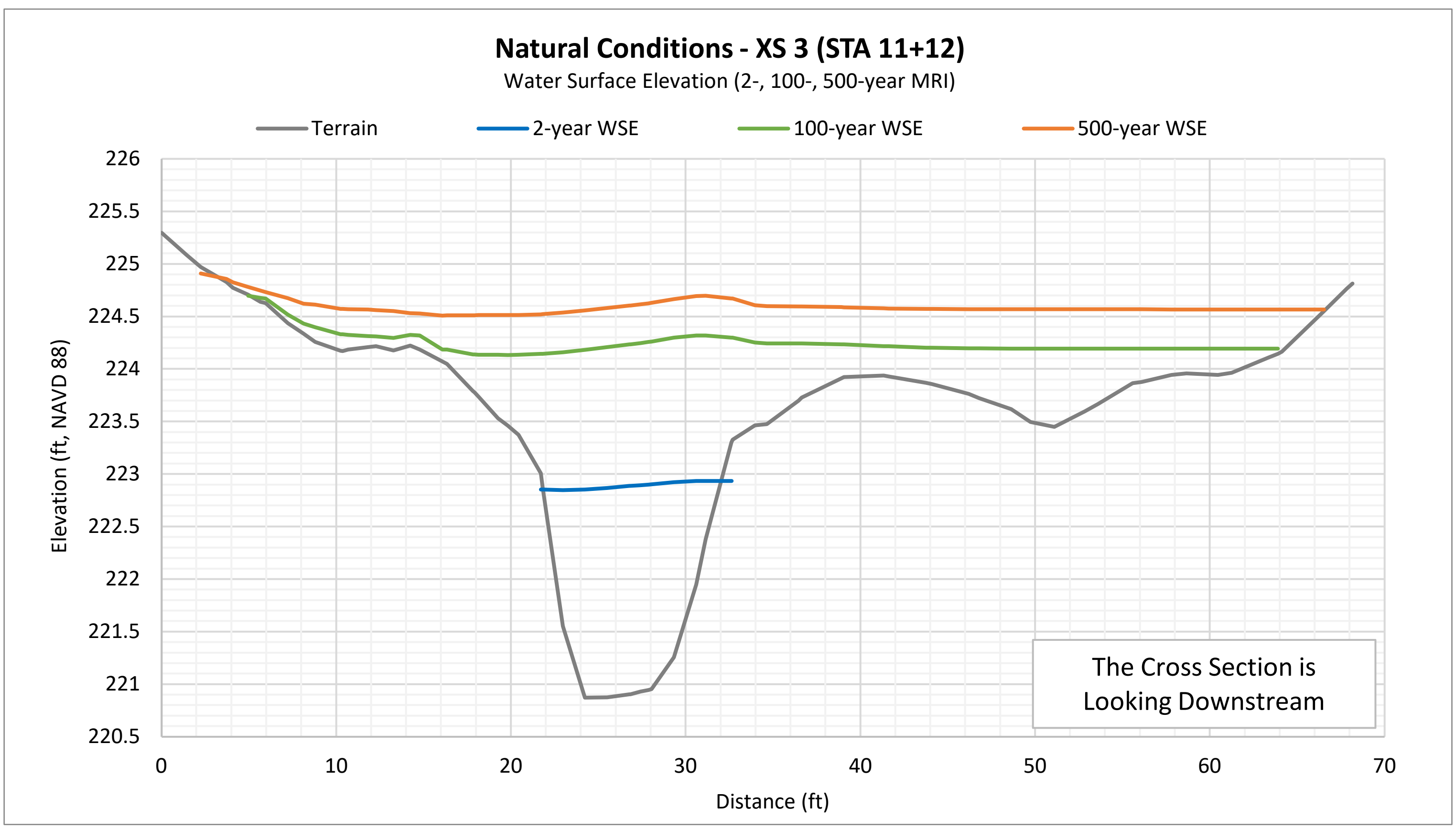

Proposed Conditions - XS 5 (STA 14+65)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
2080 100-year WSE
Elevation (ft, NAVD 88)
244
242
240
238
236
234
232
230
0
20
40
60
80
100
120
140
Distance (ft)
The Cross Section is Looking Downstream

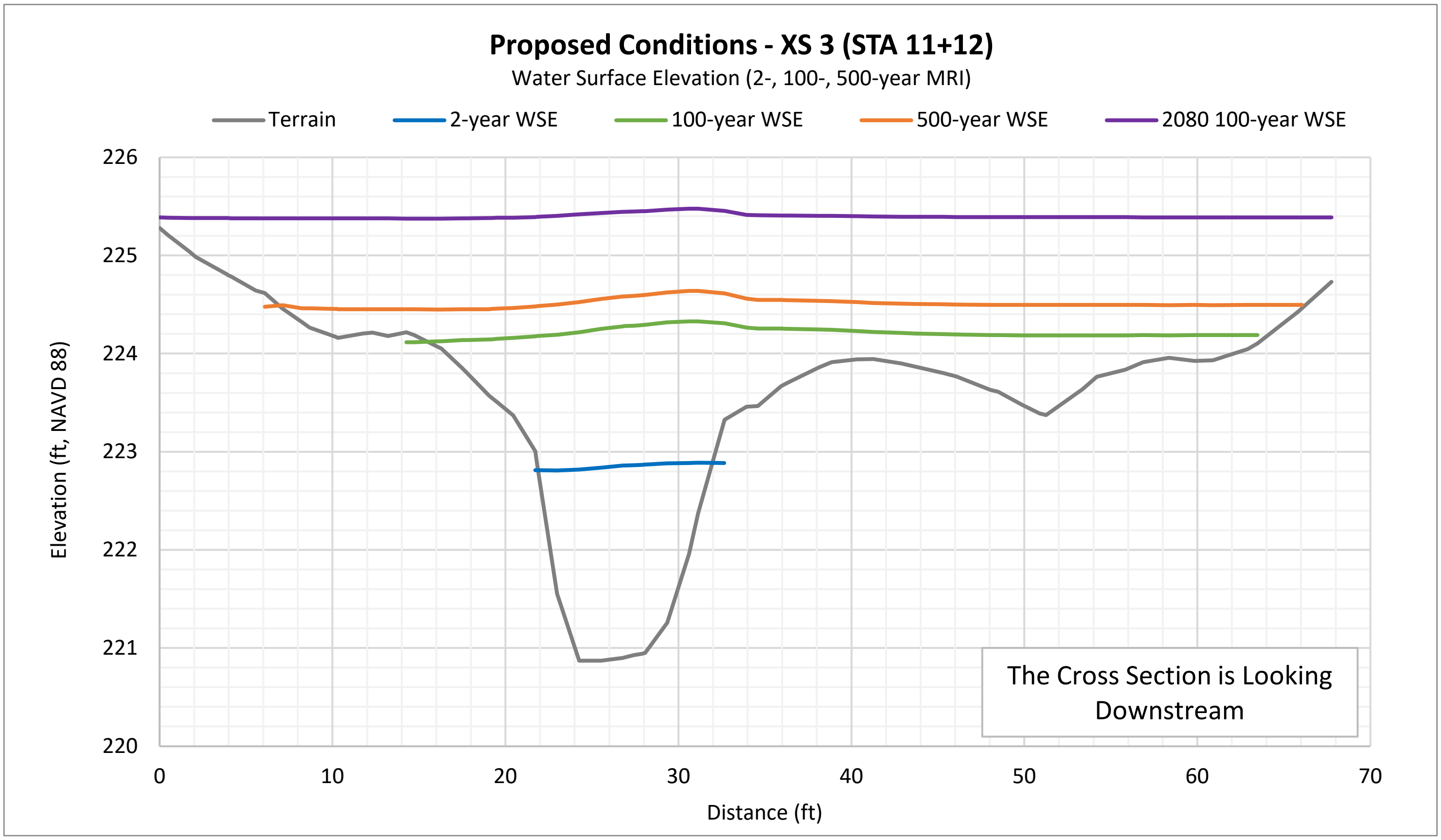

Existing Conditions - XS 4 (STA 14+30)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
Elevation (ft, NAVD 88)
242
240
238
236
234
232
230
0
20
40
60
80
100
120
Distance (ft)
The Cross Section is Looking Downstream

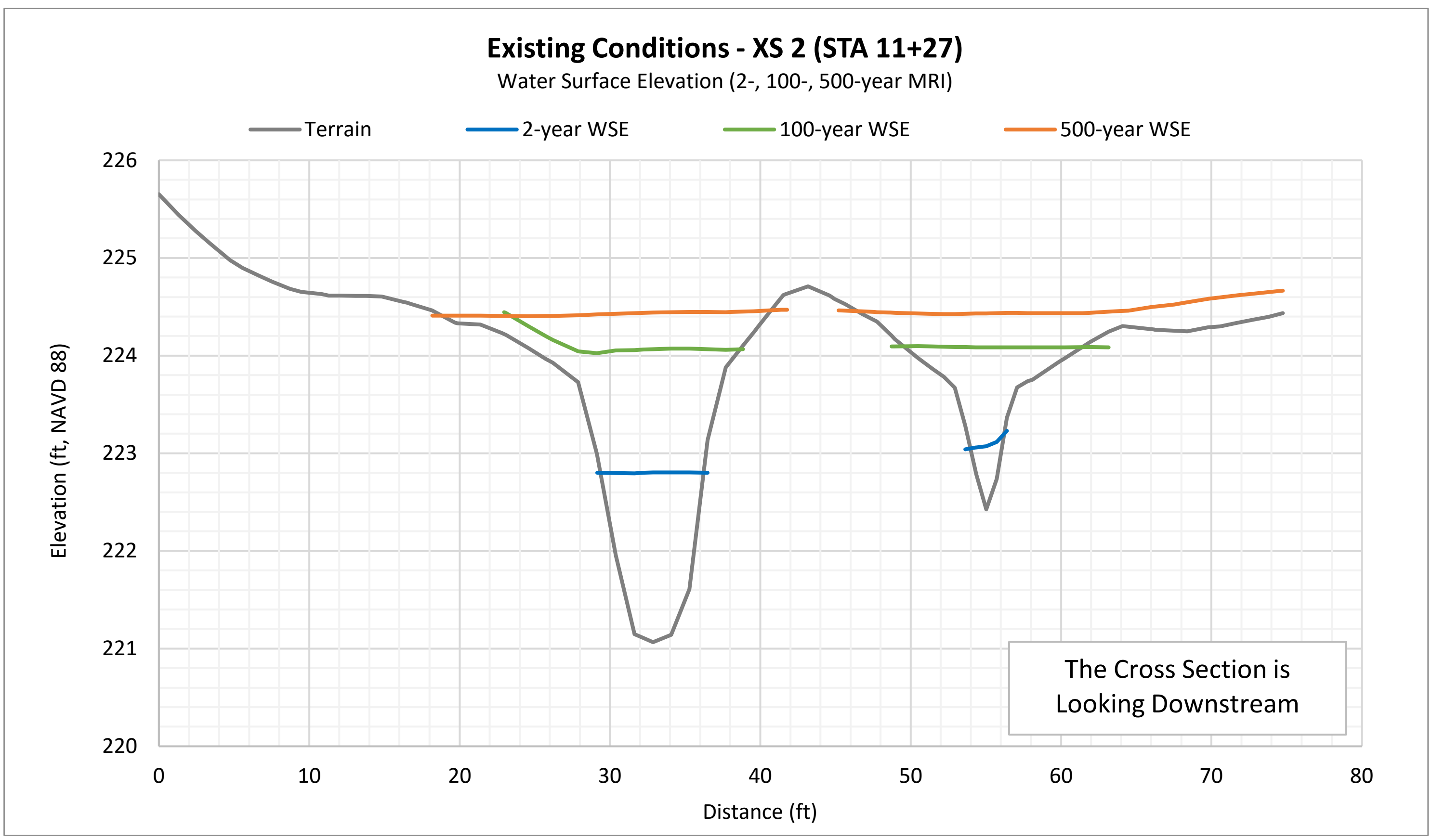

Natural Conditions - XS 4 (STA 14+30)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
Elevation (ft, NAVD 88)
242
240
238
236
234
232
230
0
20
40
60
80
100
120
Distance (ft)
The Cross Section is Looking Downstream

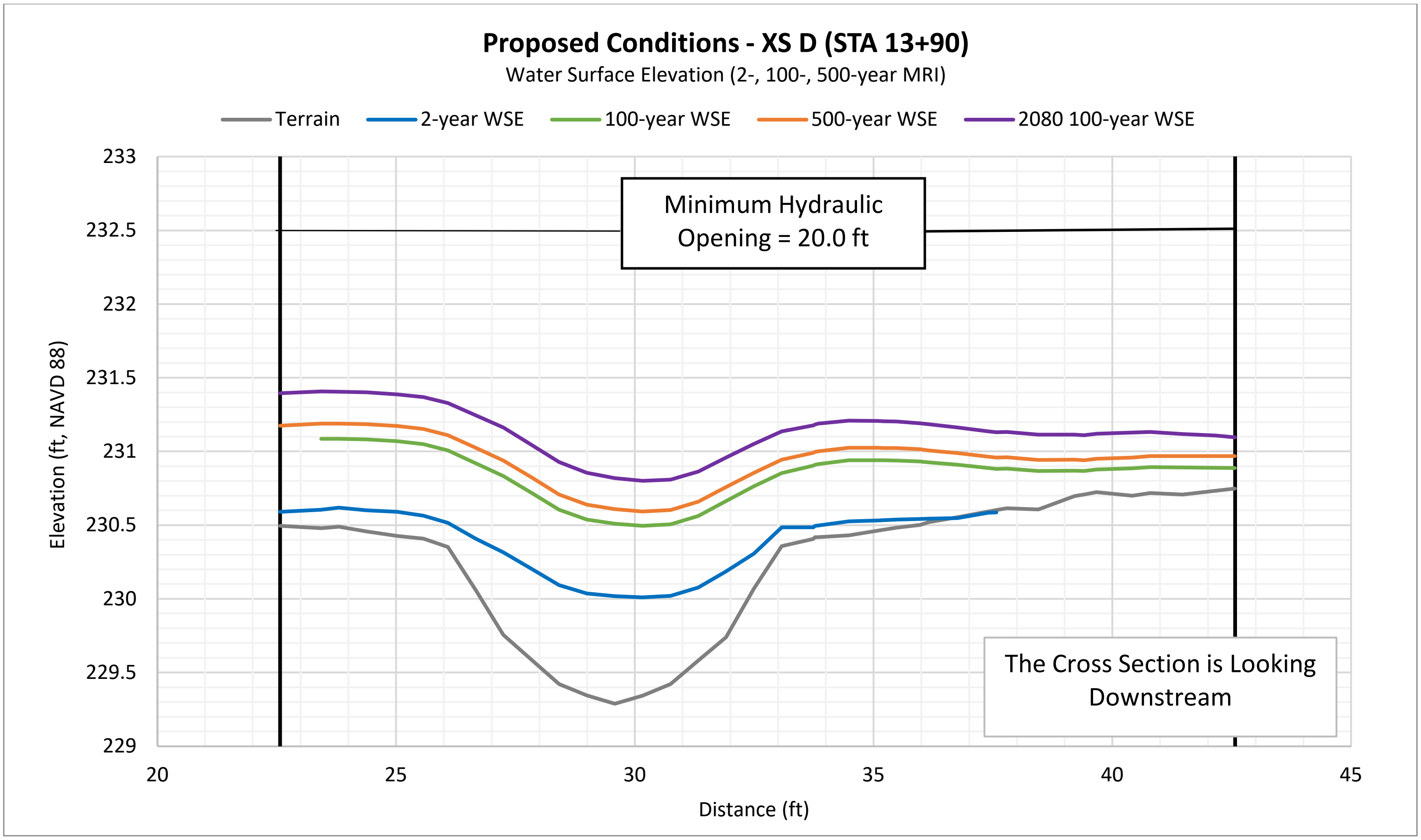

Proposed Conditions - XS 4 (STA 14+31)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
2080 100-year WSE
Elevation (ft, NAVD 88)
242
240
238
236
234
232
230
0
20
40
60
80
100
120
Distance (ft)
The Cross Section is Looking Downstream

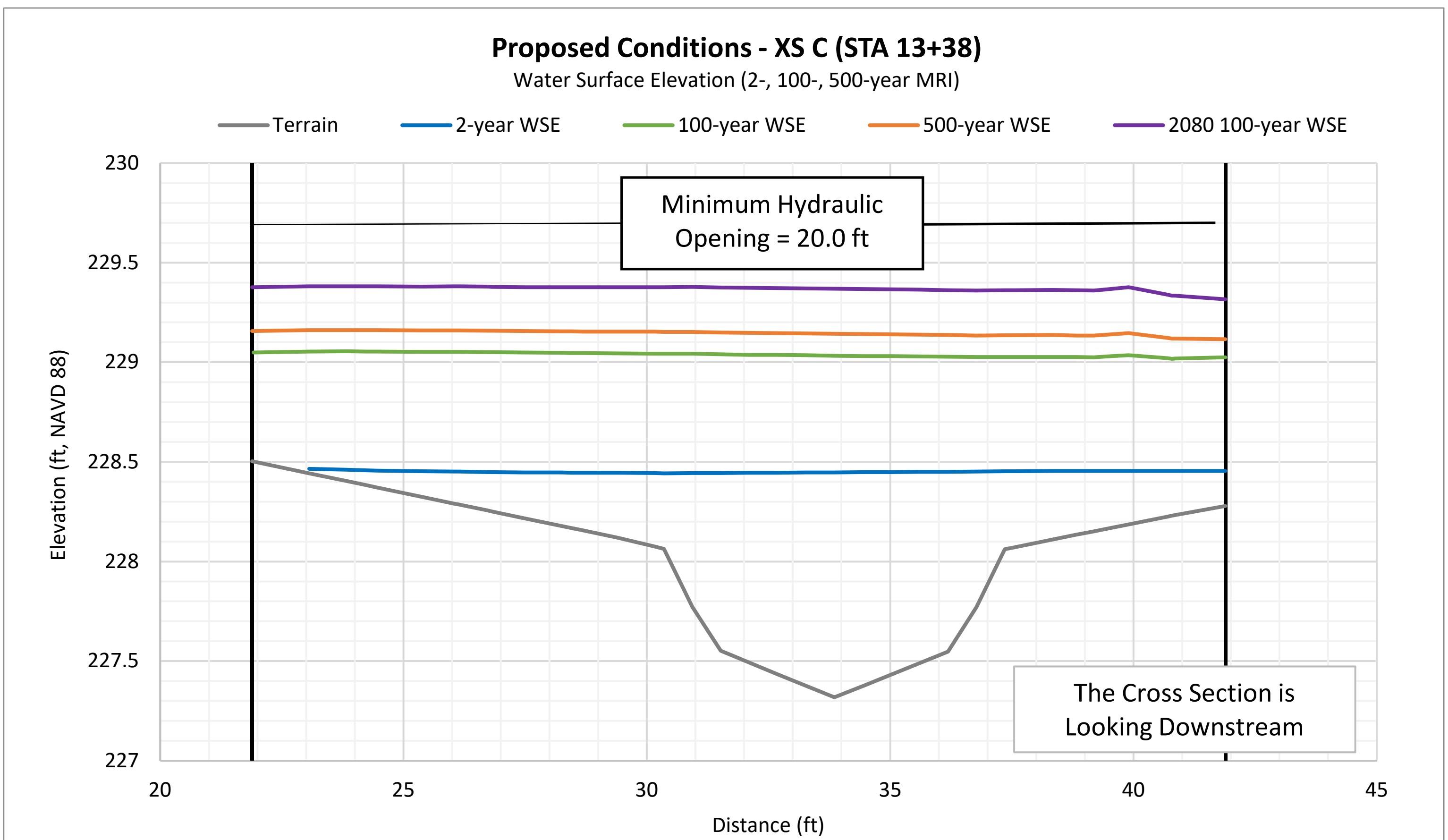

Existing Conditions - XS 3 (STA 11+12)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
Elevation (ft, NAVD 88)
226
225.5
225
224.5
224
223.5
223
222.5
222
221.5
221
220.5
0
10
20
30
40
50
60
70
Distance (ft)
The Cross Section is Looking Downstream

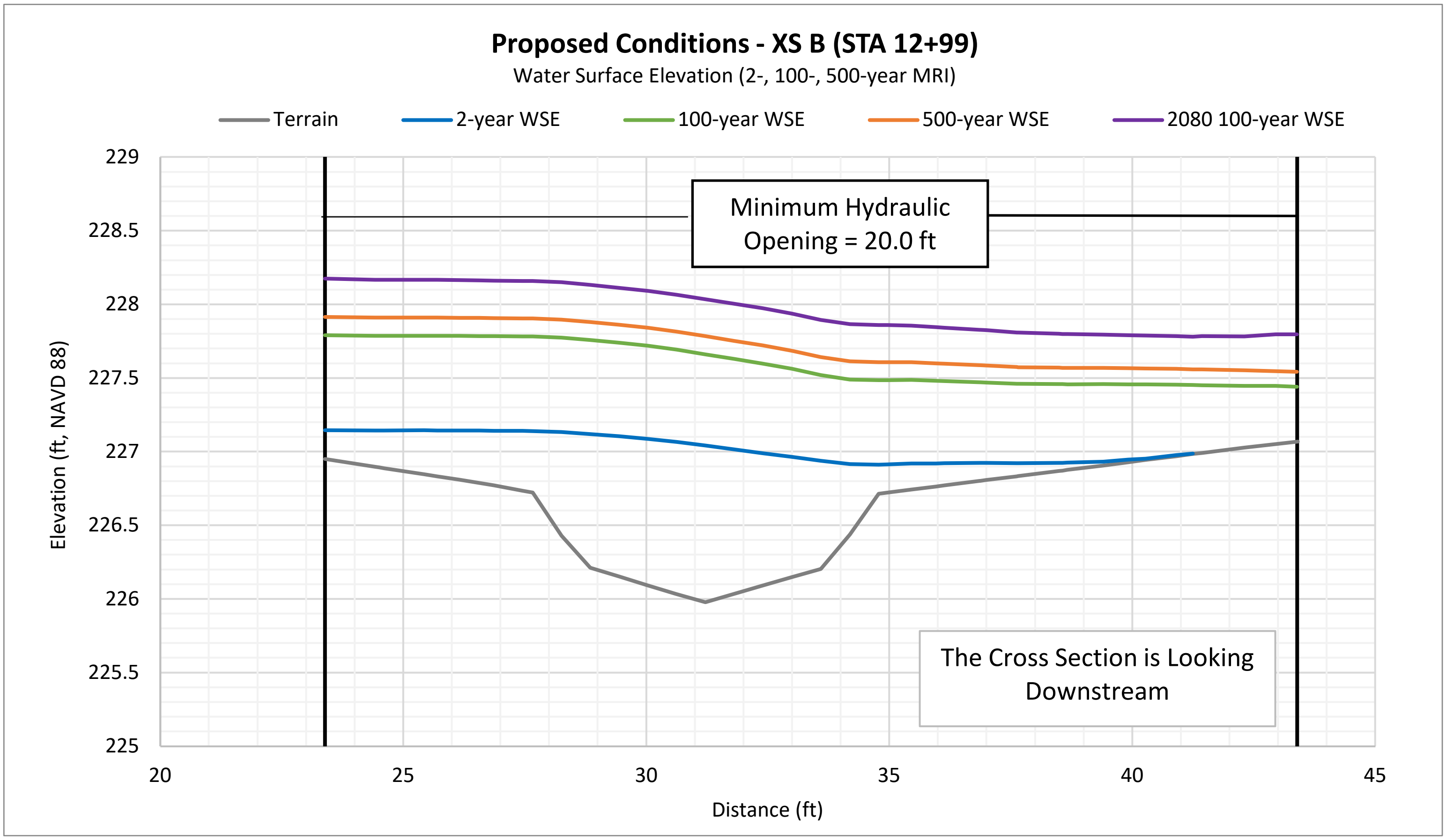

Natural Conditions - XS 3 (STA 11+12)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
Elevation (ft, NAVD 88)
226
225.5
225
224.5
224
223.5
223
222.5
222
221.5
221
220.5
0
10
20
30
40
50
60
70
Distance (ft)
The Cross Section is Looking Downstream

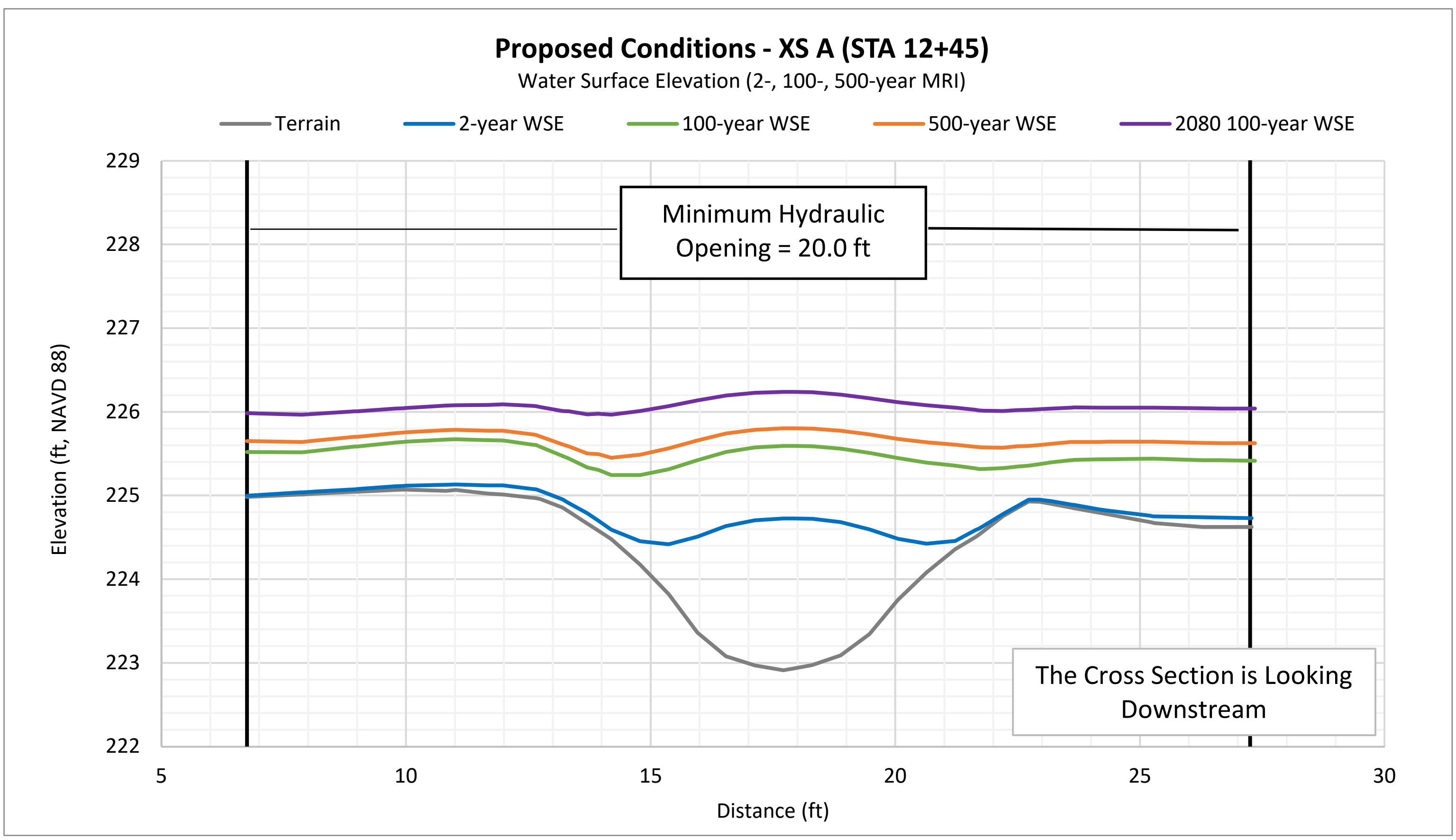

Proposed Conditions - XS 3 (STA 11+12)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
2080 100-year WSE
Elevation (ft, NAVD 88)
226
225
224
223
222
221
220
0
10
20
30
40
50
60
70
Distance (ft)
The Cross Section is Looking Downstream

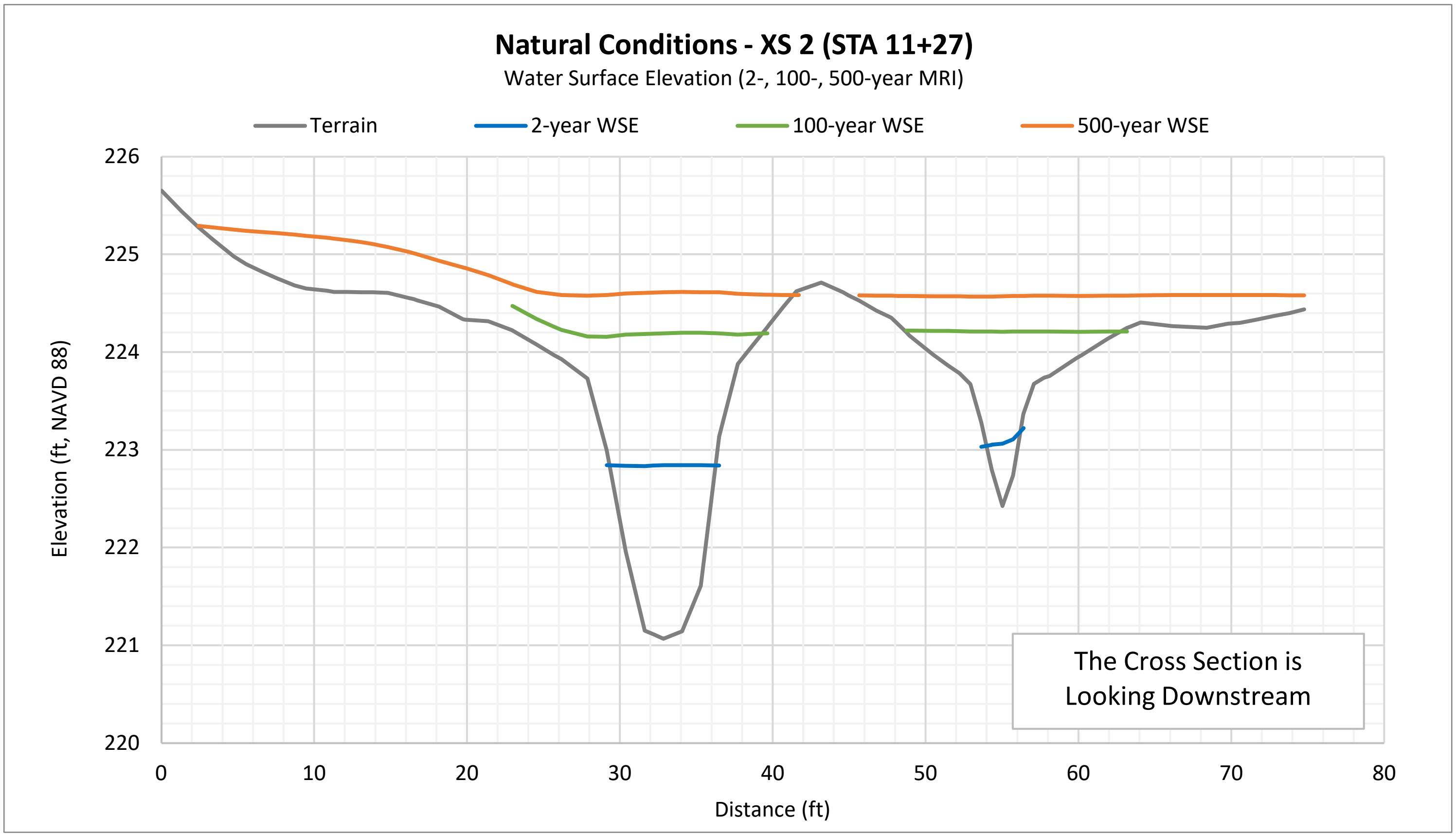

Existing Conditions - XS 2 (STA 11+27)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
Elevation (ft, NAVD 88)
226
225
224
223
222
221
220
0
10
20
30
40
50
60
70
80
Distance (ft)
The Cross Section is Looking Downstream

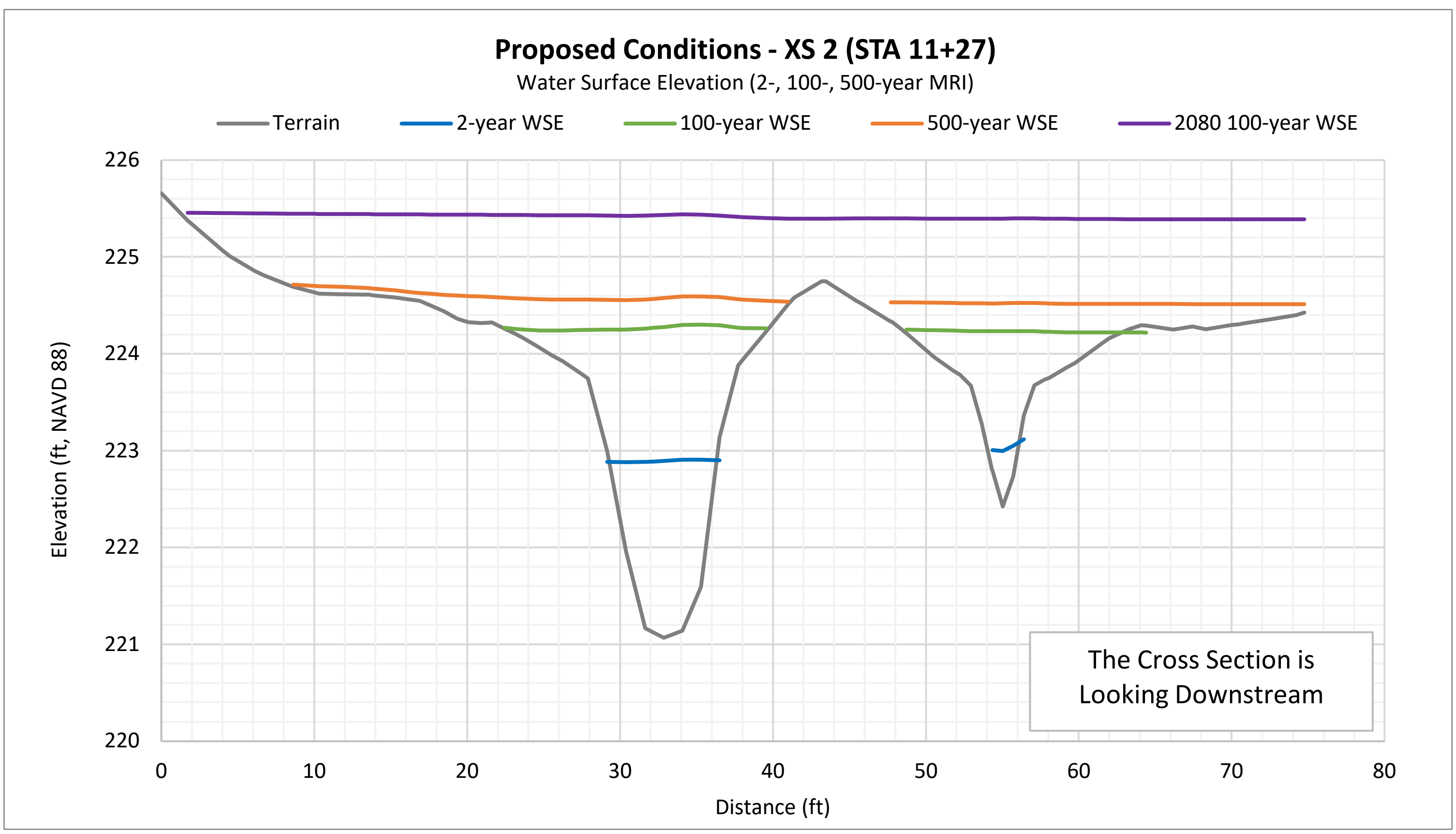

Proposed Conditions - XS D (STA 13+90)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
2080 100-year WSE
Minimum Hydraulic Opening = 20.0 ft
The Cross Section is Looking Downstream
Elevation (ft, NAVD 88)
Distance (ft)
233
232.5
232
231.5
231
230.5
230
229.5
229
20
25
30
35
40
45

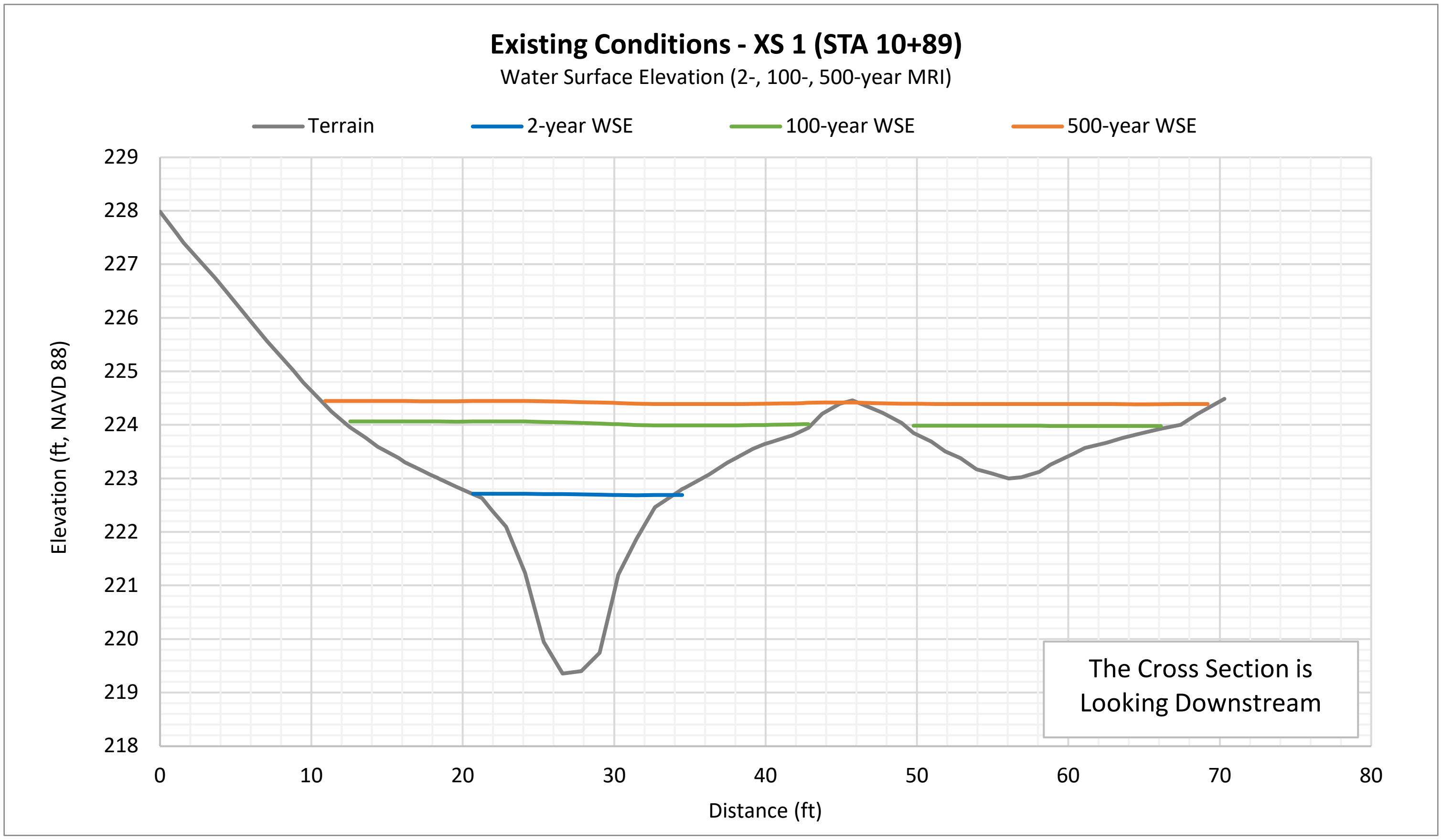

Proposed Conditions - XS C (STA 13+38)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
2080 100-year WSE
Minimum Hydraulic Opening = 20.0 ft
The Cross Section is Looking Downstream
Elevation (ft, NAVD 88)
Distance (ft)
230
229.5
229
228.5
228
227.5
227
20
25
30
35
40
45

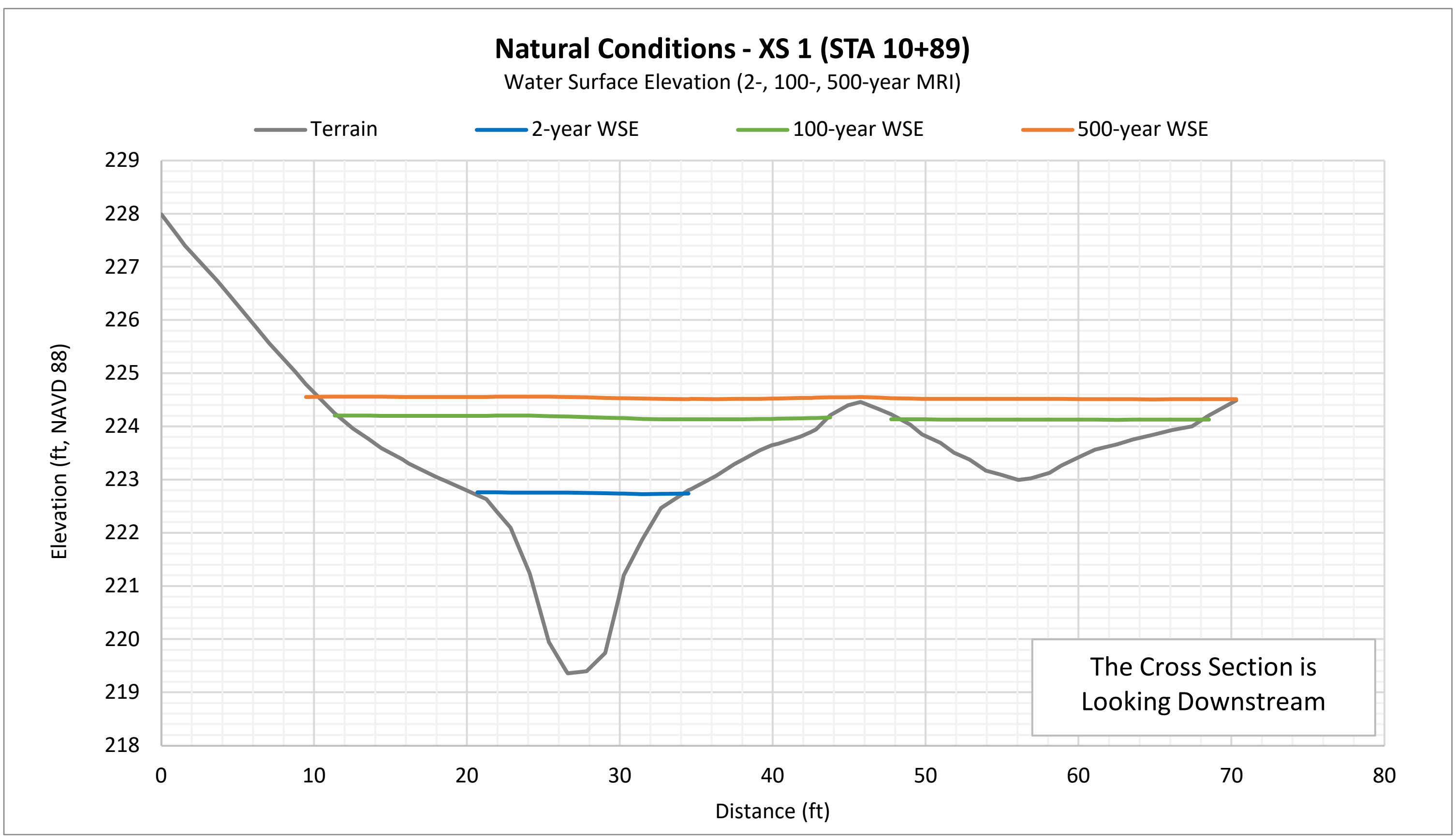

Proposed Conditions - XS B (STA 12+99)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
2080 100-year WSE
Minimum Hydraulic Opening = 20.0 ft
The Cross Section is Looking Downstream
Elevation (ft, NAVD 88)
Distance (ft)
229
228.5
228
227.5
227
226.5
226
225.5
225
20
25
30
35
40
45

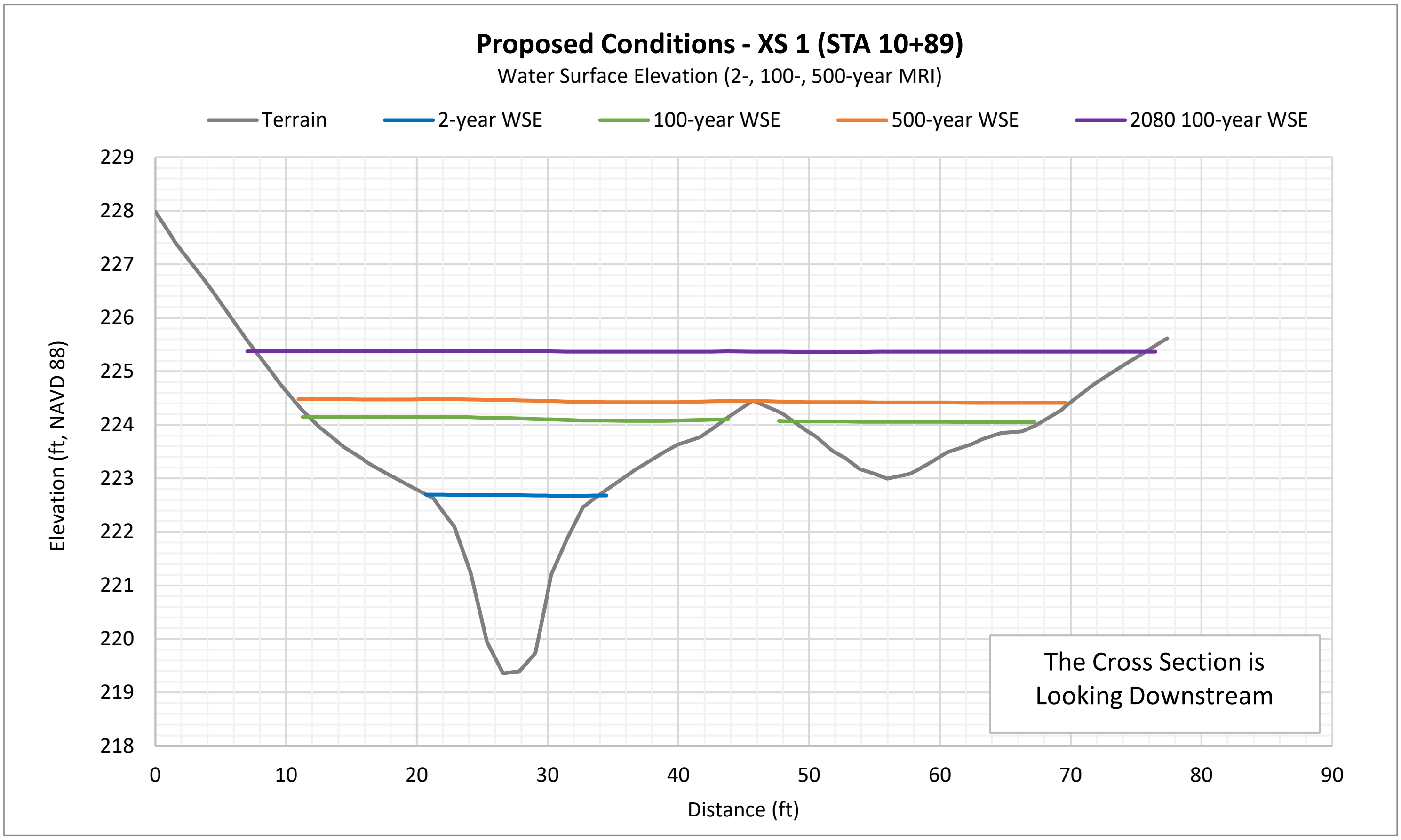

Proposed Conditions - XS A (STA 12+45)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
2080 100-year WSE
Minimum Hydraulic Opening = 20.0 ft
The Cross Section is Looking Downstream
Elevation (ft, NAVD 88)
Distance (ft)
229
228
227
226
225
224
223
222
5
10
15
20
25
30


Natural Conditions - XS 2 (STA 11+27)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
Elevation (ft, NAVD 88)
226
225
224
223
222
221
220
0
10
20
30
40
50
60
70
80
Distance (ft)
The Cross Section is Looking Downstream


Proposed Conditions - XS 2 (STA 11+27)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
2080 100-year WSE
Elevation (ft, NAVD 88)
226
225
224
223
222
221
220
0
10
20
30
40
50
60
70
80
Distance (ft)
The Cross Section is Looking Downstream

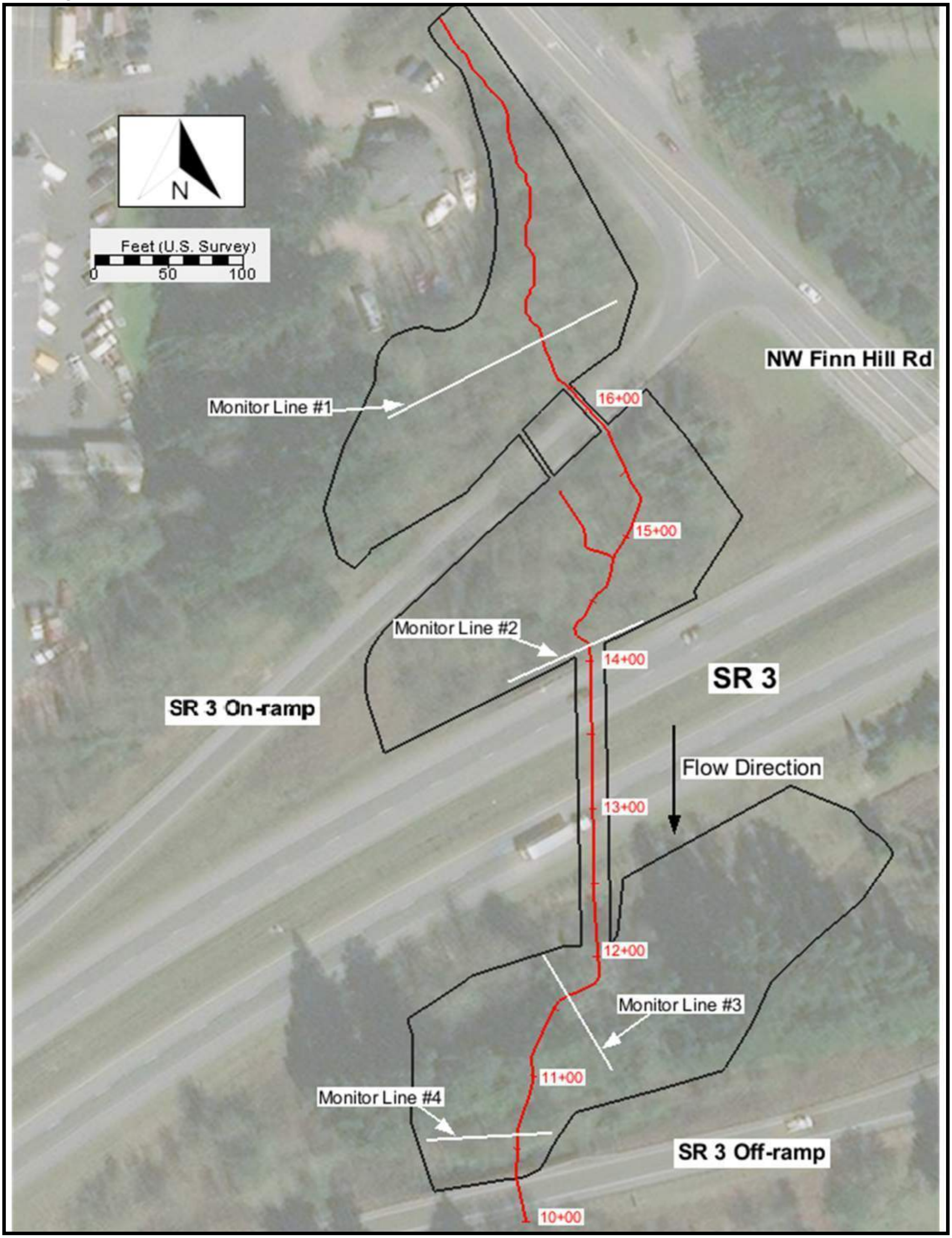

Existing Conditions - XS 1 (STA 10+89)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
Elevation (ft, NAVD 88)
229
228
227
226
225
224
223
222
221
220
219
218
0
10
20
30
40
50
60
70
80
Distance (ft)
The Cross Section is Looking Downstream


Natural Conditions - XS 1 (STA 10+89)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
Elevation (ft, NAVD 88)
229
228
227
226
225
224
223
222
221
220
219
218
0
10
20
30
40
50
60
70
80
Distance (ft)
The Cross Section is Looking Downstream

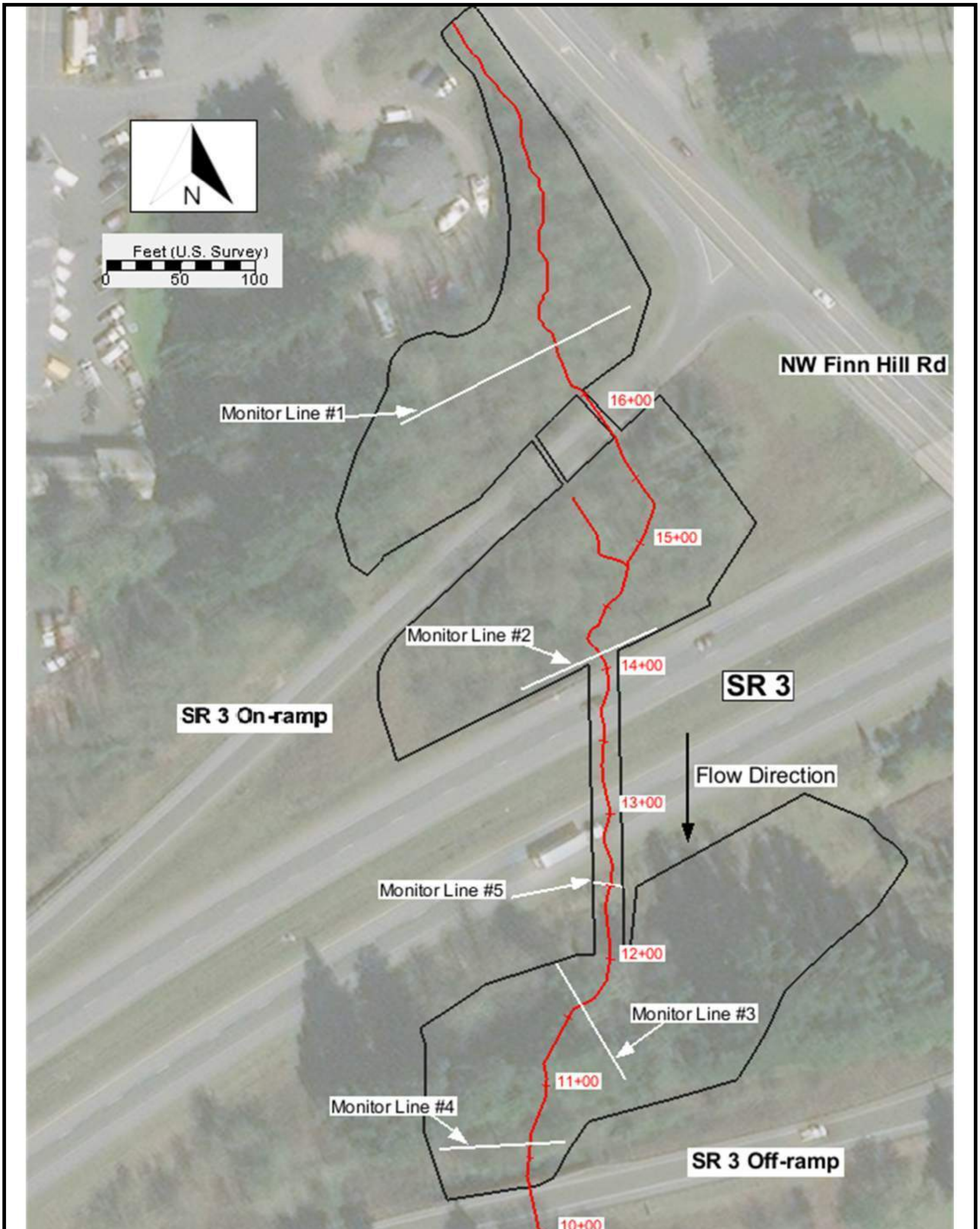

Proposed Conditions - XS 1 (STA 10+89)
Water Surface Elevation (2-, 100-, 500-year MRI)
Terrain
2-year WSE
100-year WSE
500-year WSE
2080 100-year WSE
Elevation (ft, NAVD 88)
229
228
227
226
225
224
223
222
221
220
219
218
0
10
20
30
40
50
60
70
80
90
Distance (ft)
The Cross Section is Looking Downstream

Appendix I: SRH-2D Model Stability and Continuity

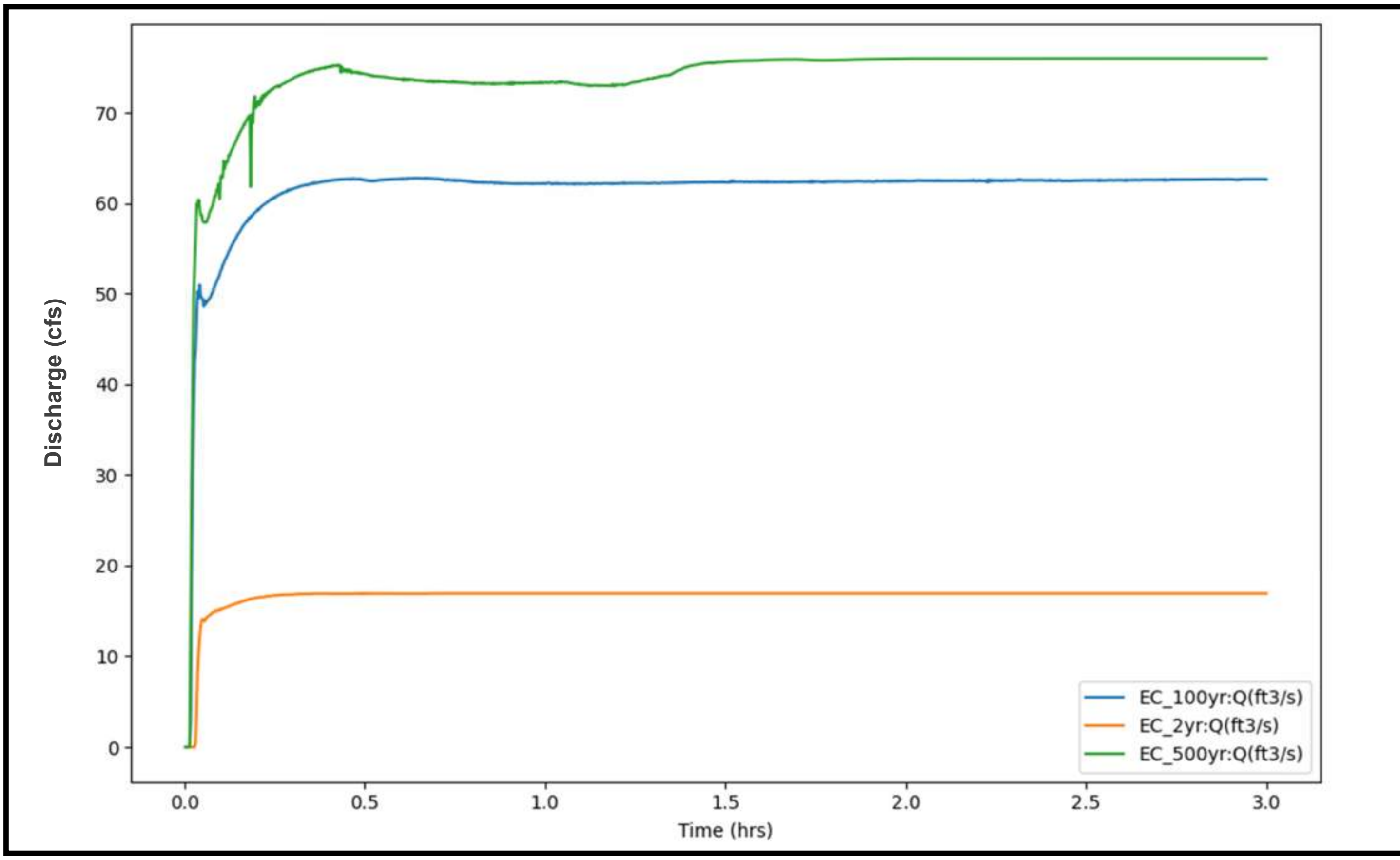
Existing and Natural Condition — Monitor Line Locations



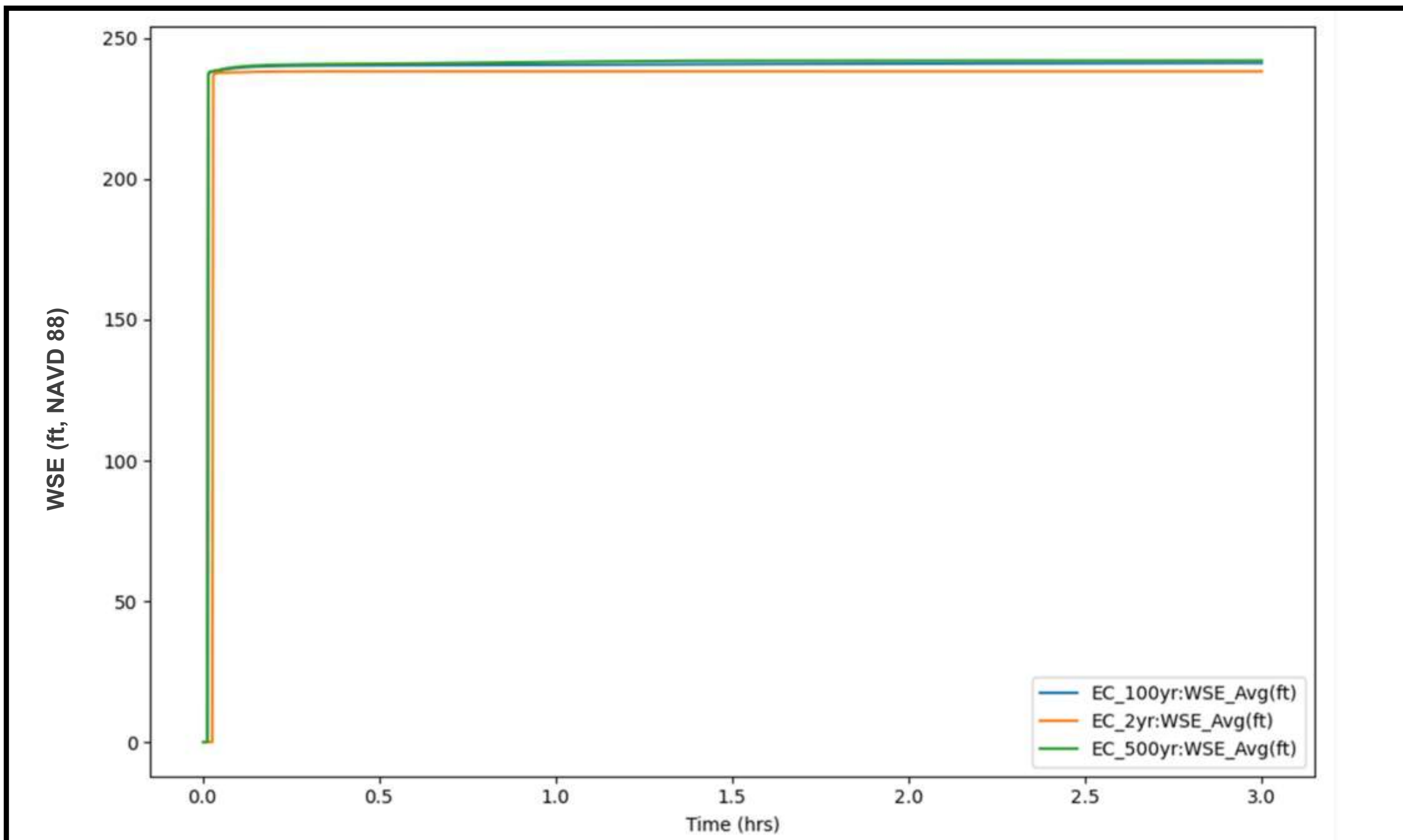
Proposed Condition — Monitor Line Locations



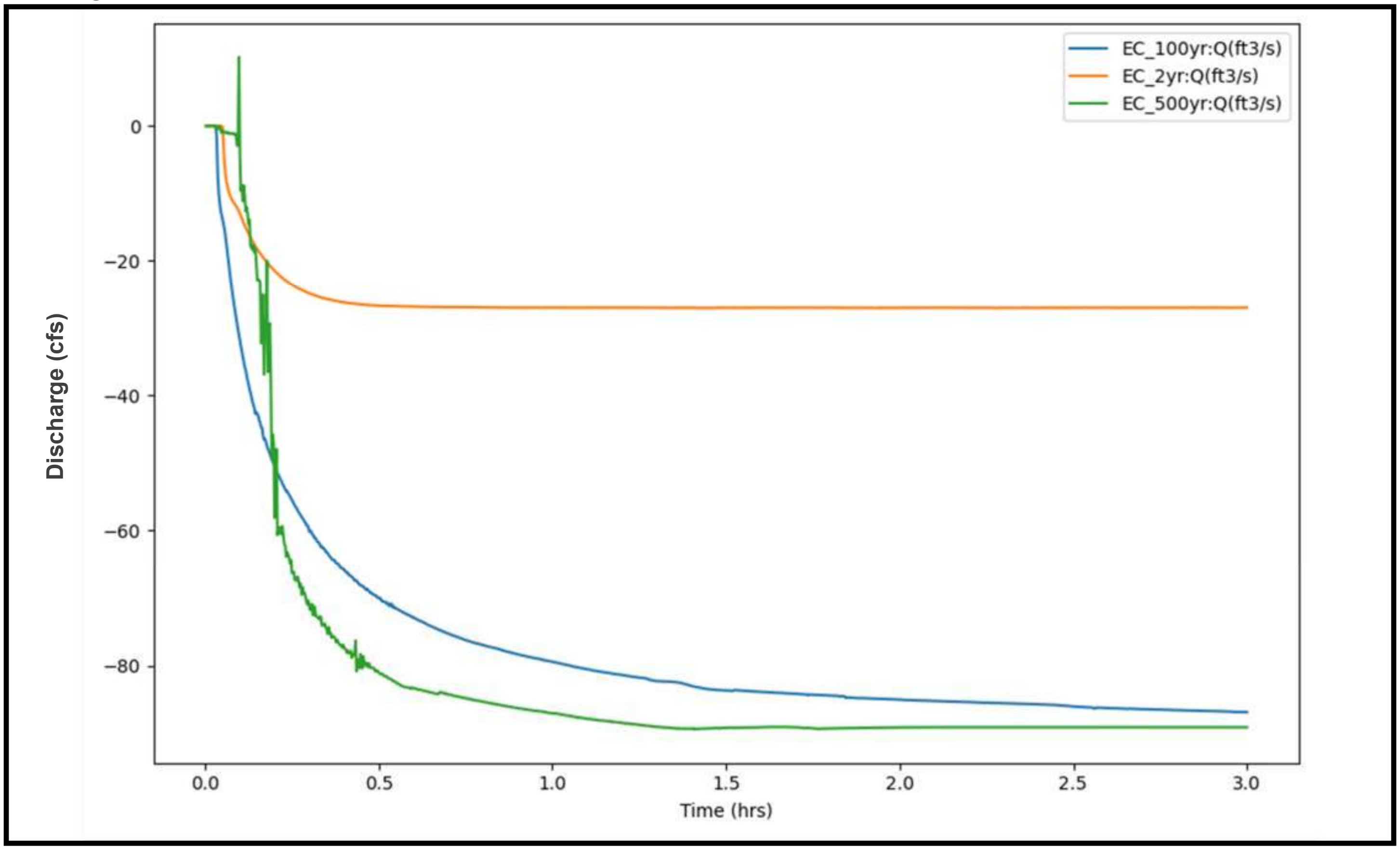
Existing Condition — Monitor Line 1 Flow vs. Time Plot



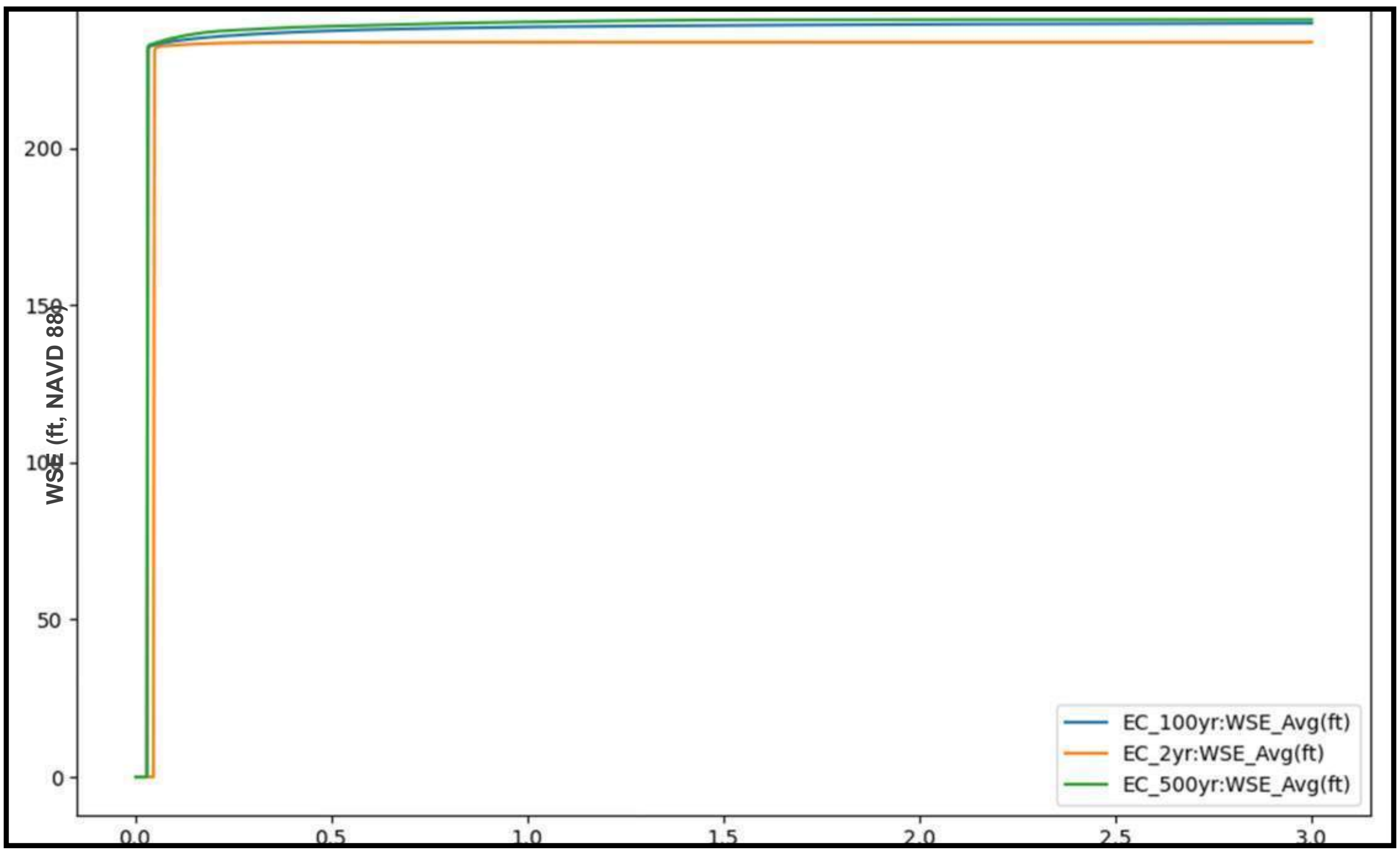
Existing Condition —Monitor Line 1 WSE vs. Time Plot



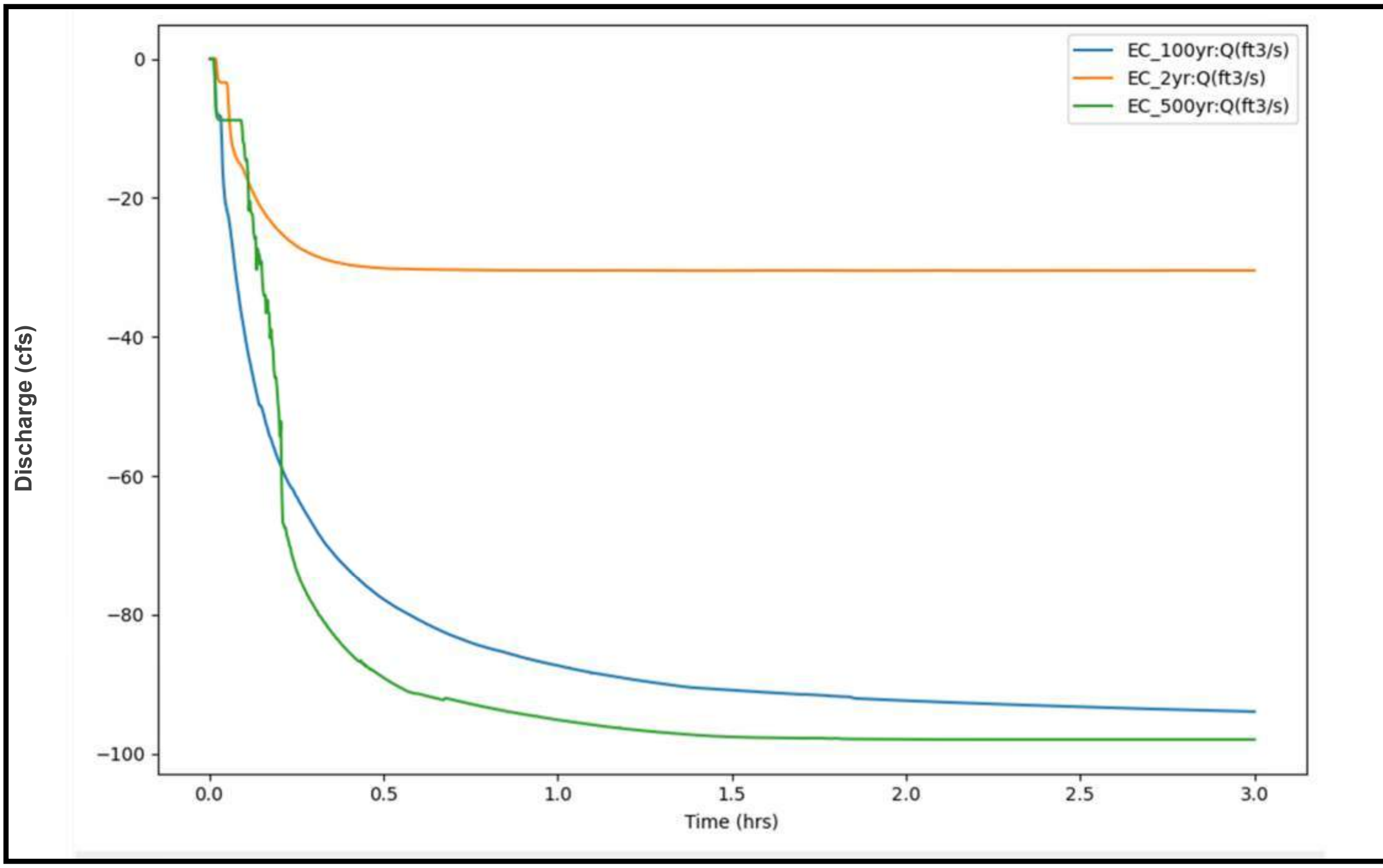
Existing Condition — Monitor Line 2 Flow vs. Time Plot



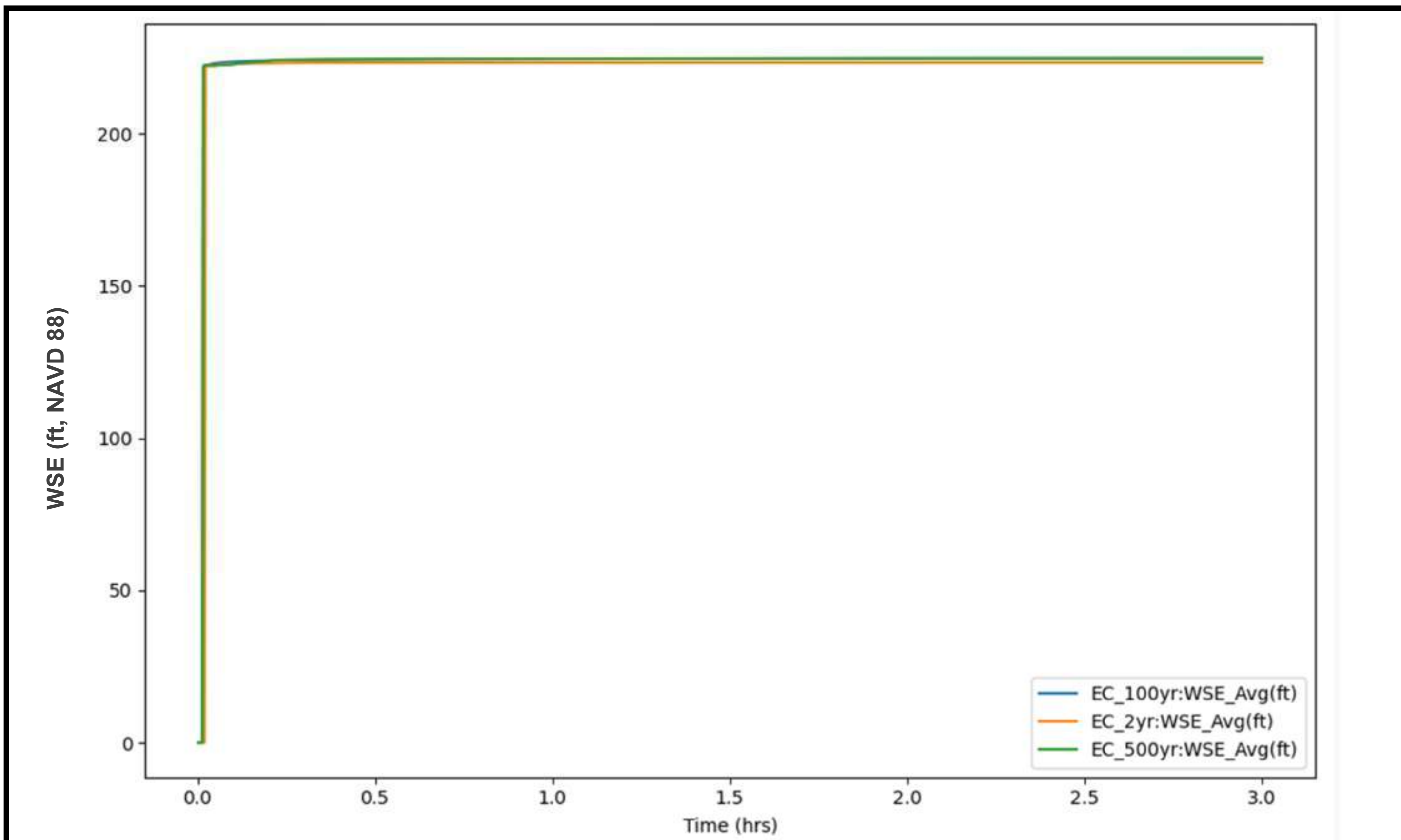
Existing Condition —Monitor Line 2 WSE vs. Time Plot



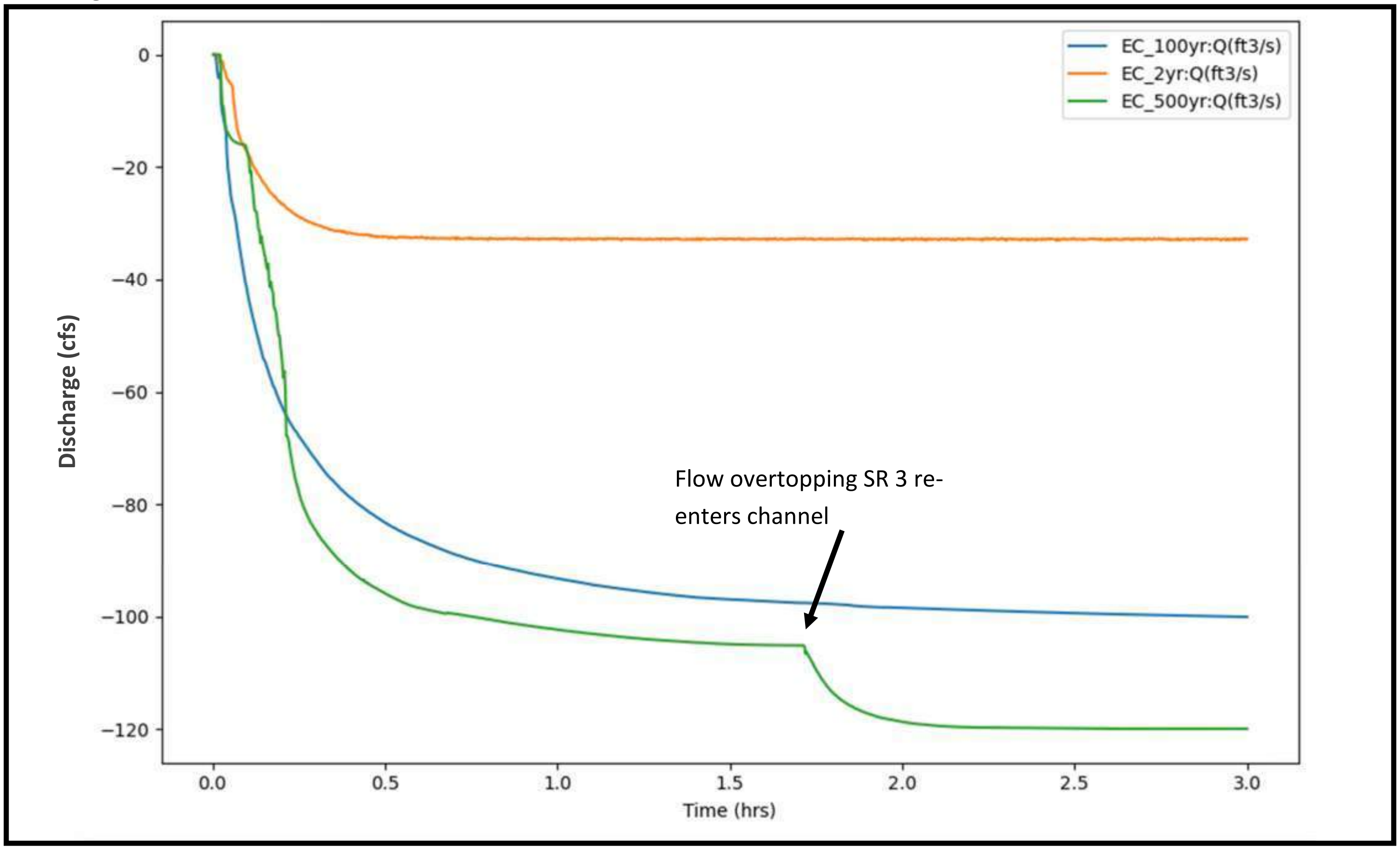
Existing Condition — Monitor Line 3 Flow vs. Time Plot



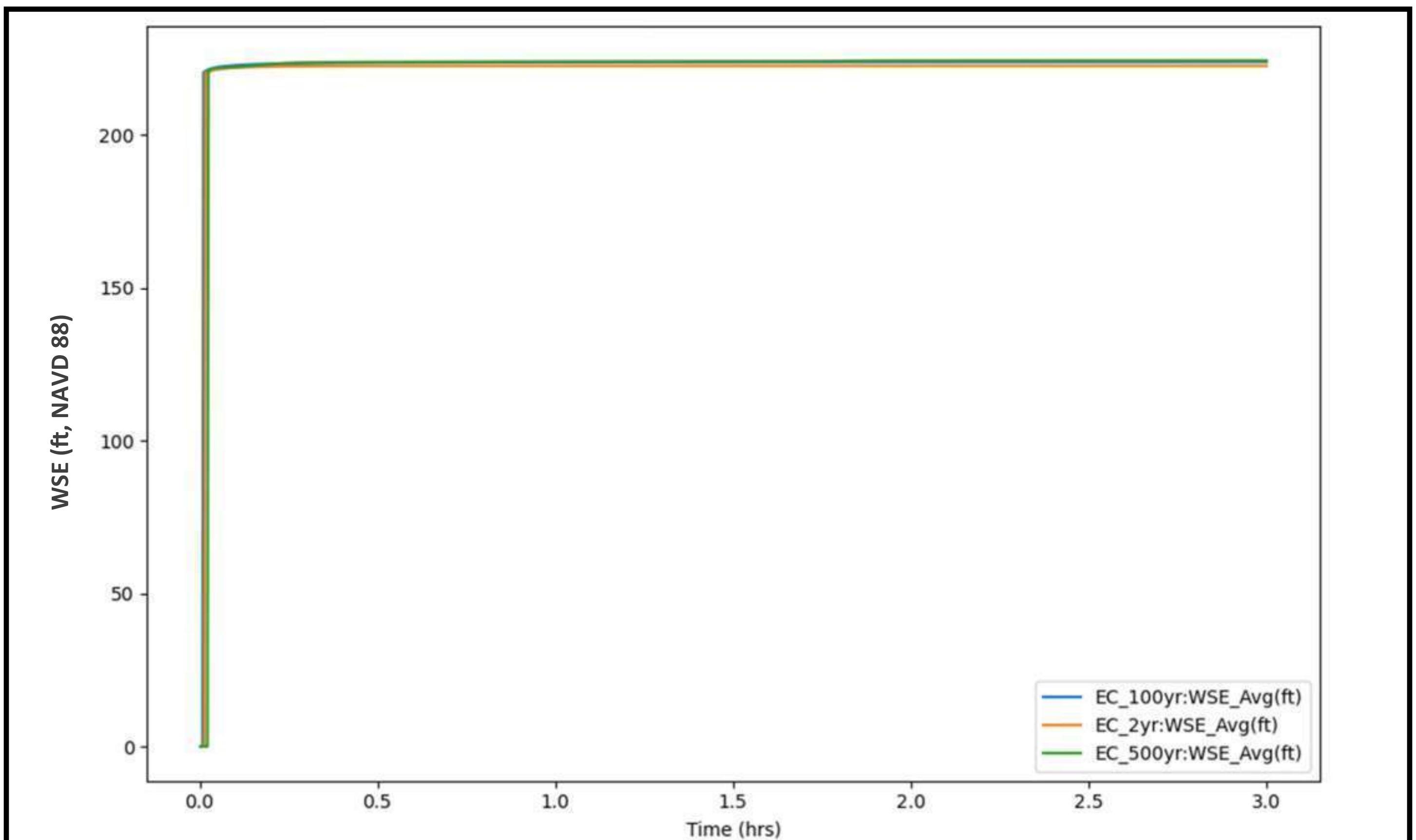
Existing Condition —Monitor Line 3 WSE vs. Time Plot



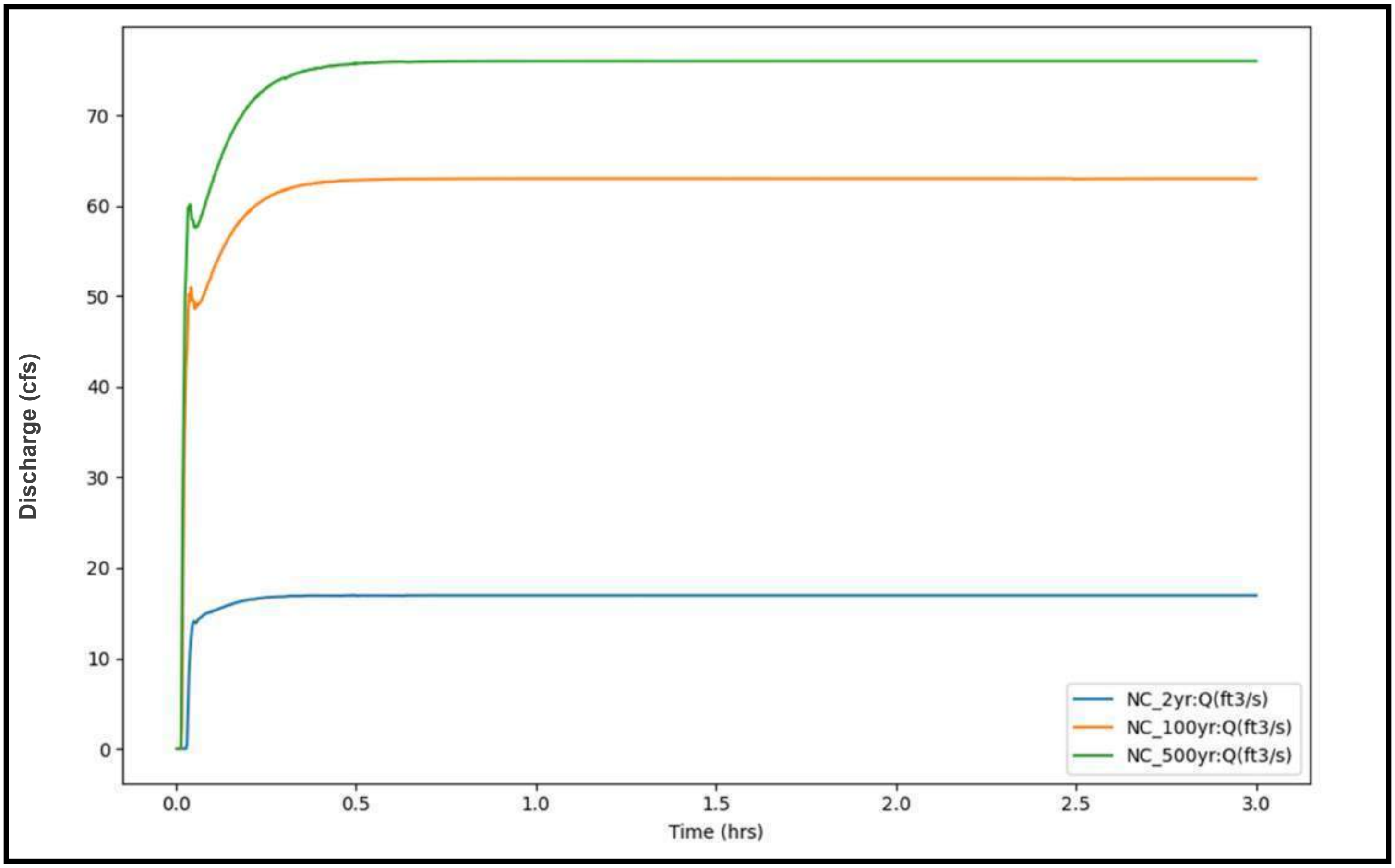
Existing Condition — Monitor Line 4 Flow vs. Time Plot



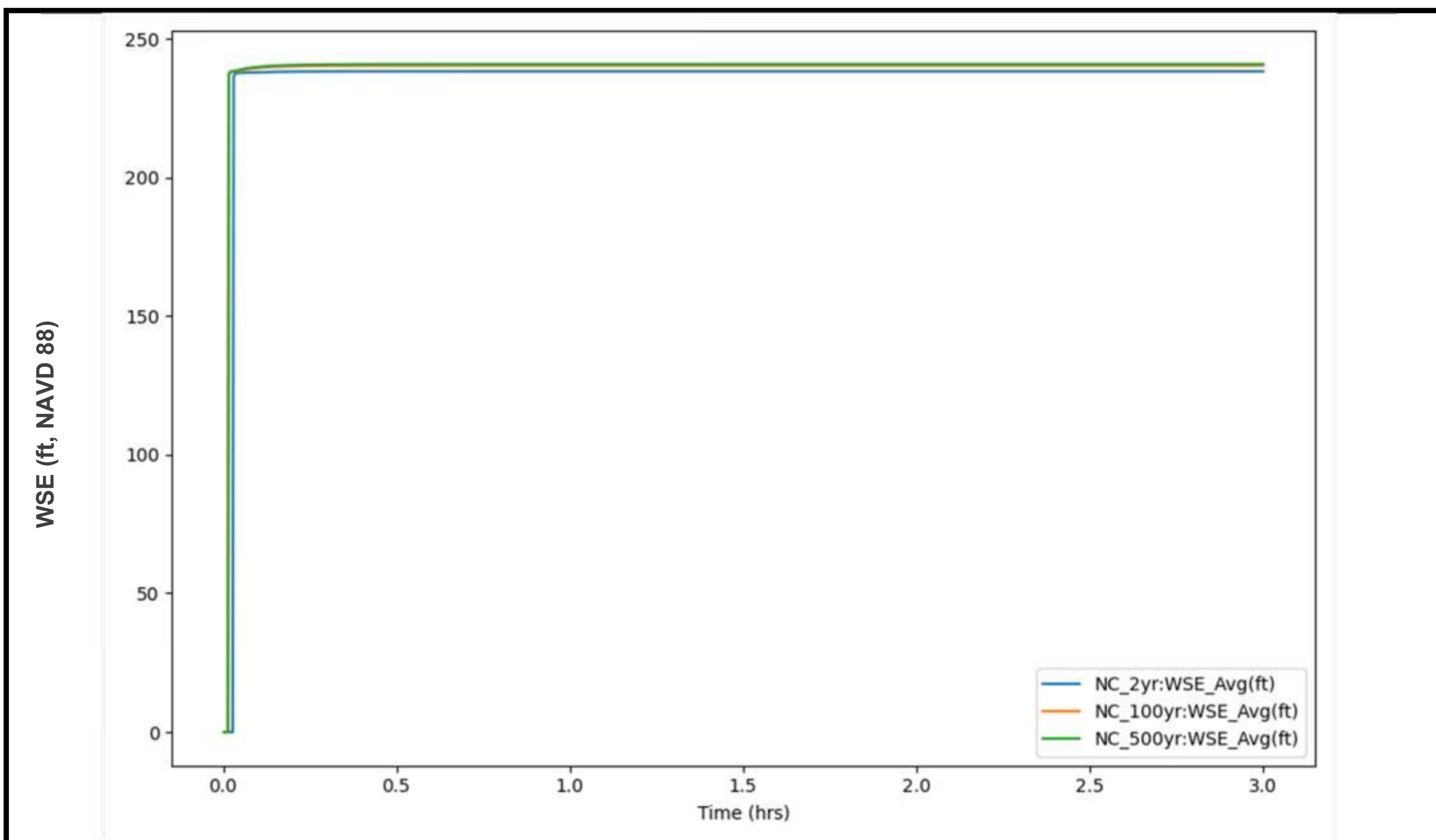
Existing Condition —Monitor Line 4 WSE vs. Time Plot



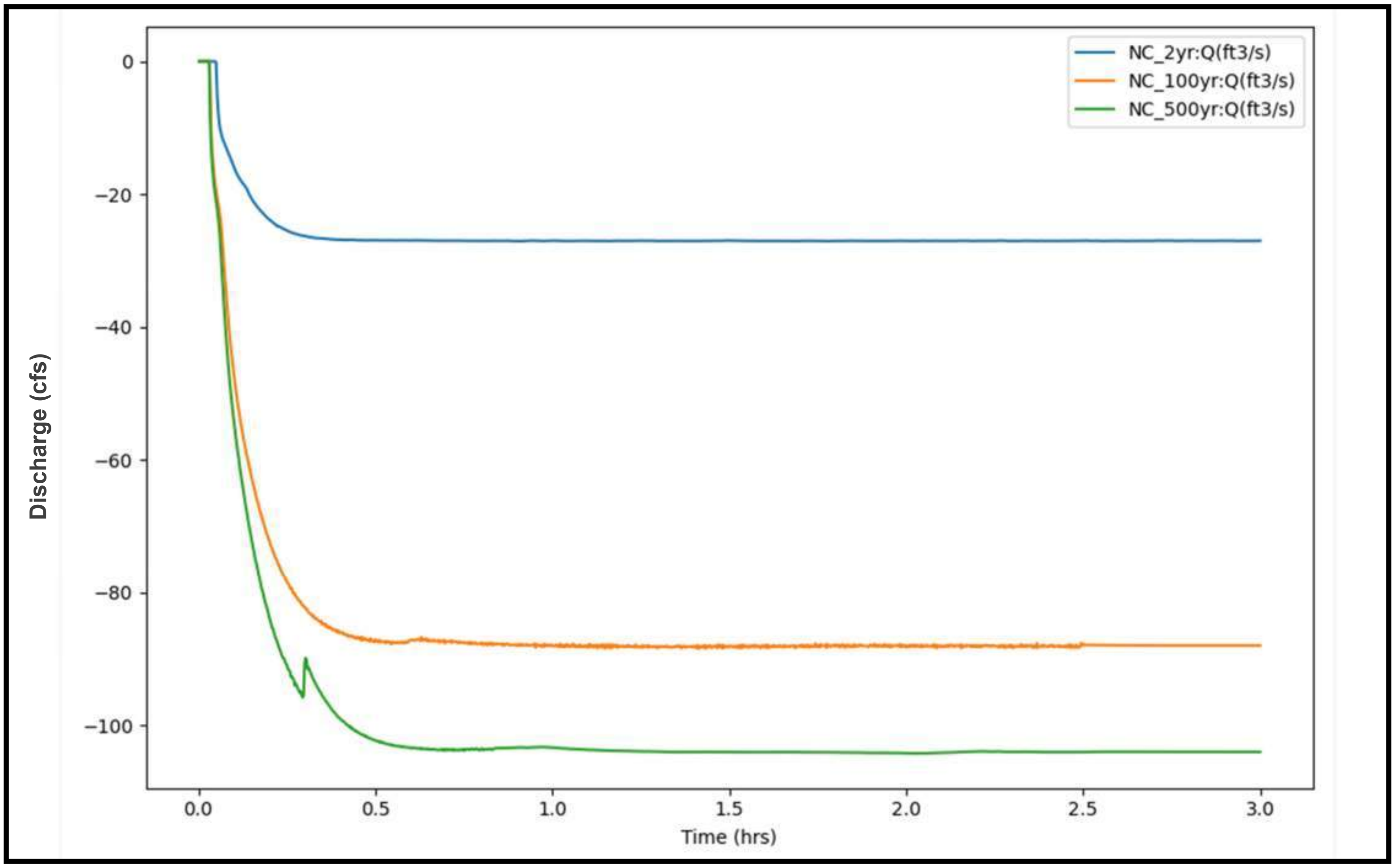
Natural Condition — Monitor Line 1 Flow vs. Time Plot



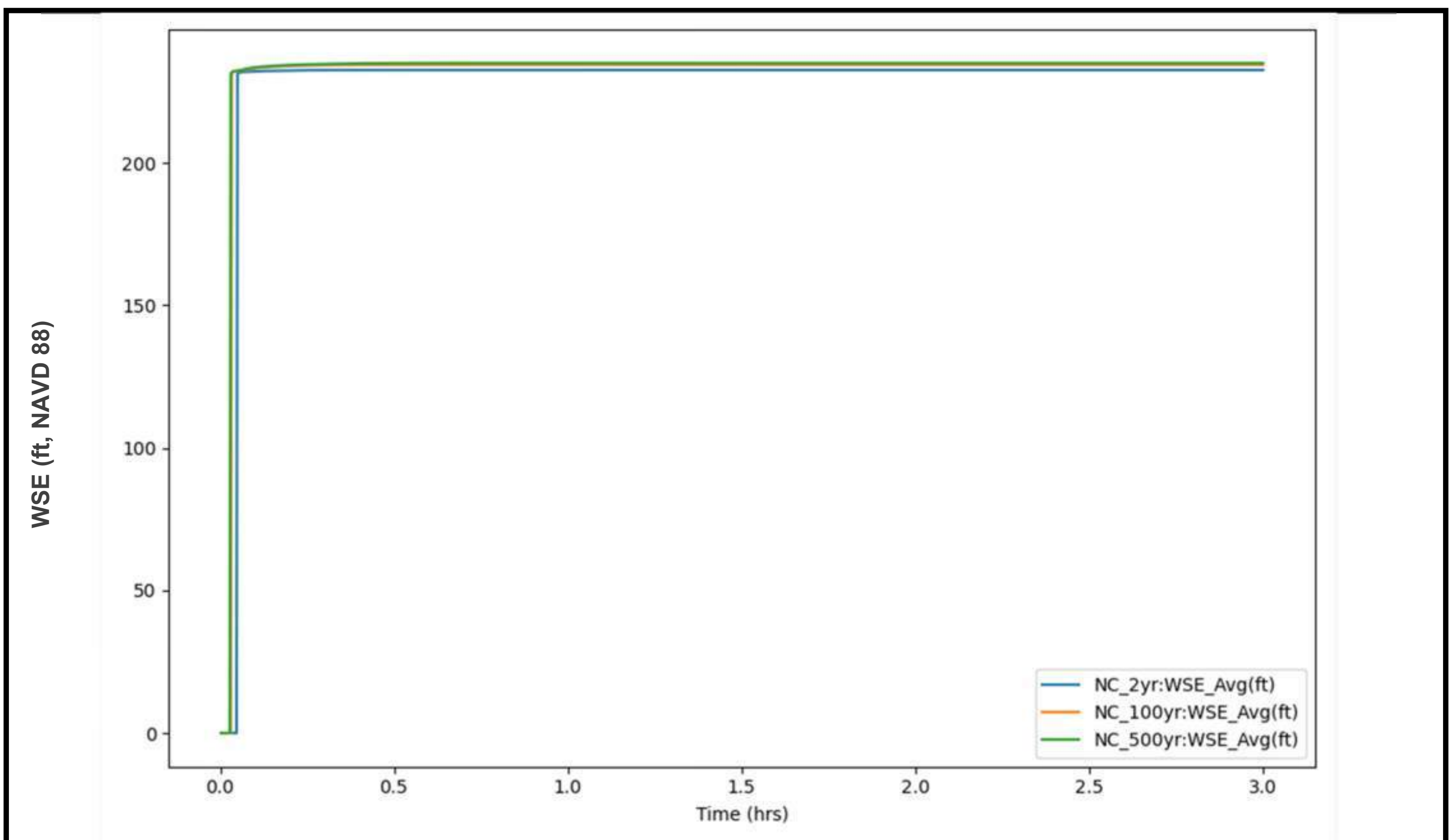
Natural Condition —Monitor Line 1 WSE vs. Time Plot



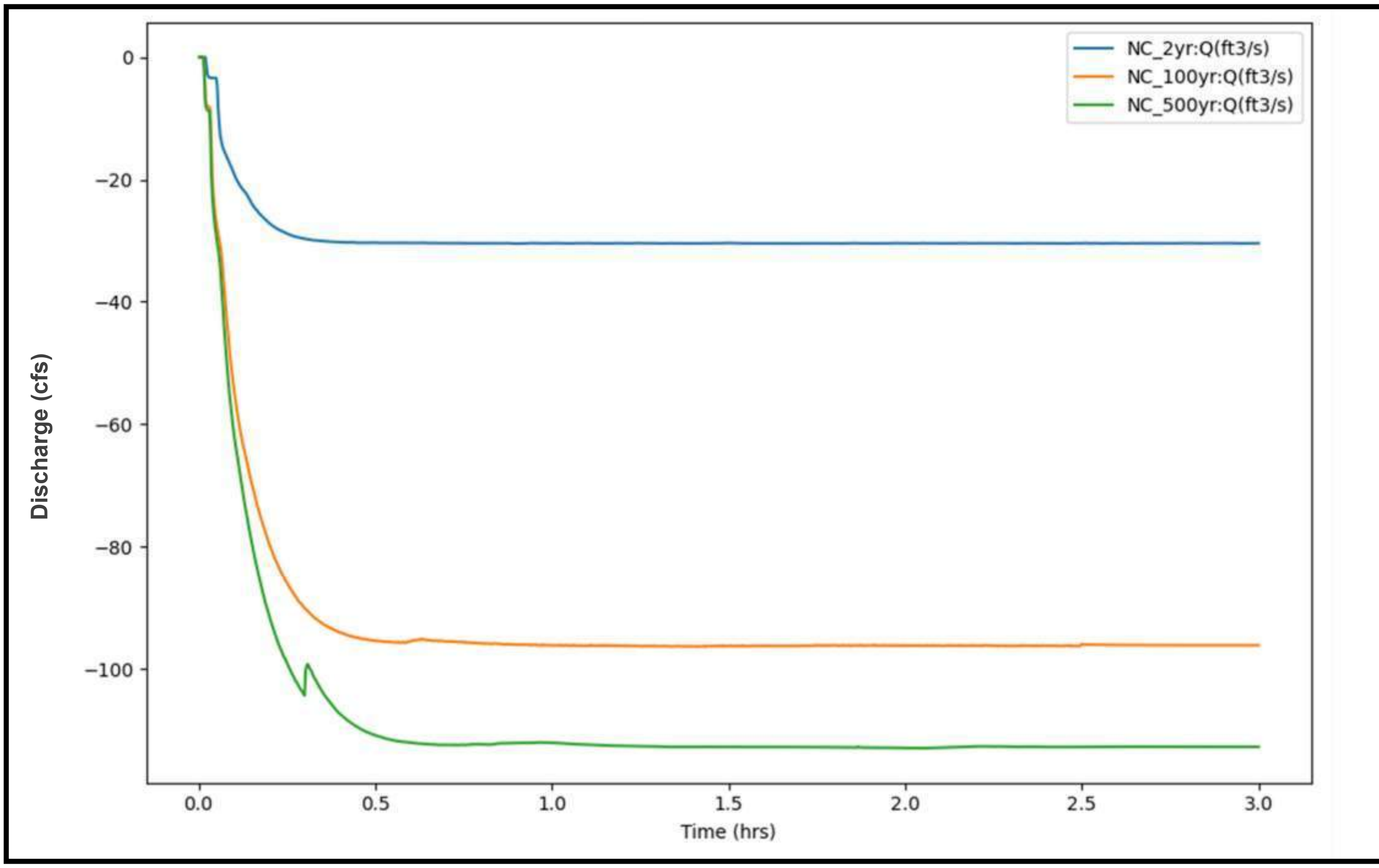
Natural Condition — Monitor Line 2 Flow vs. Time Plot



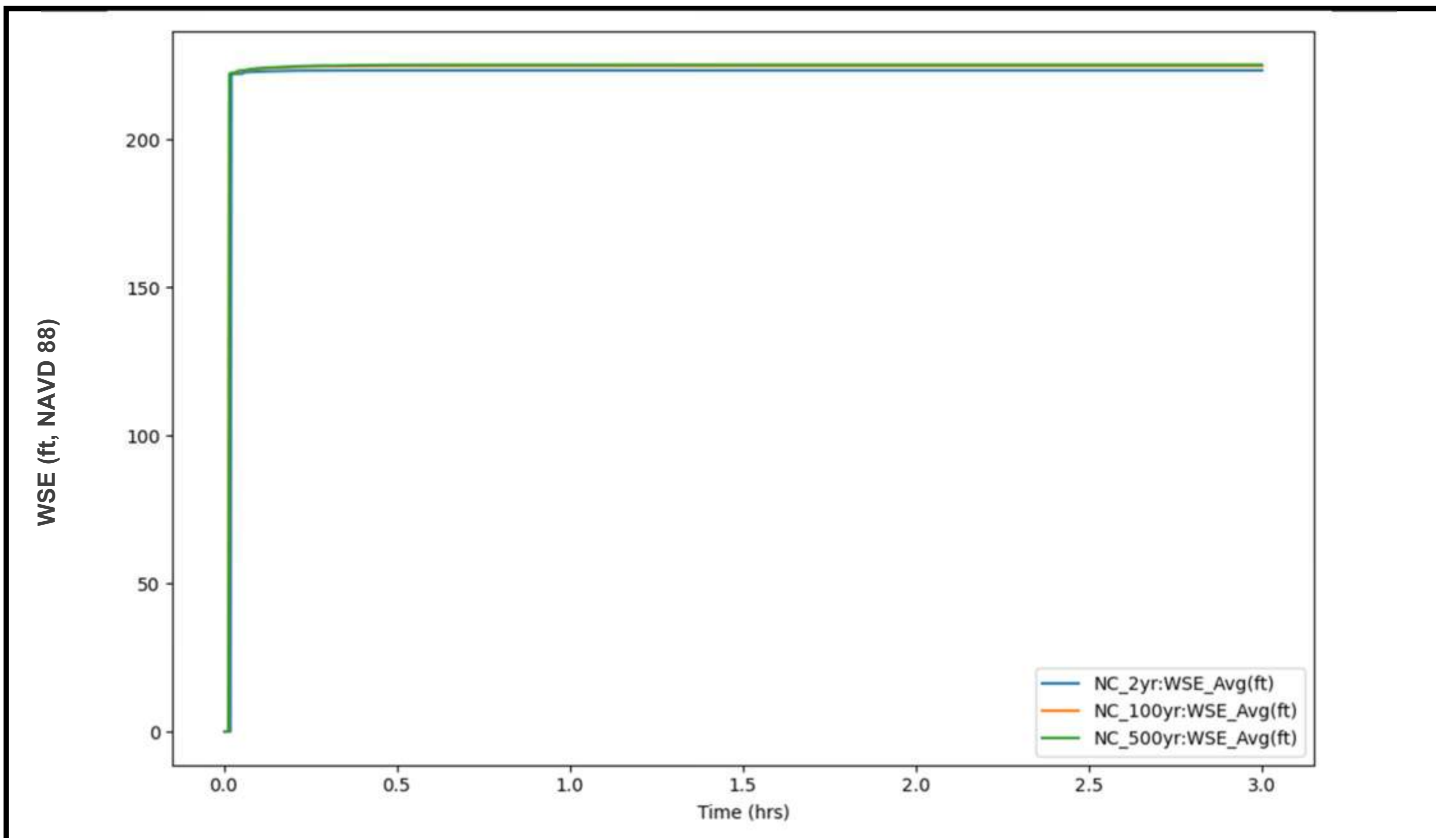
Natural Condition —Monitor Line 2 WSE vs. Time Plot



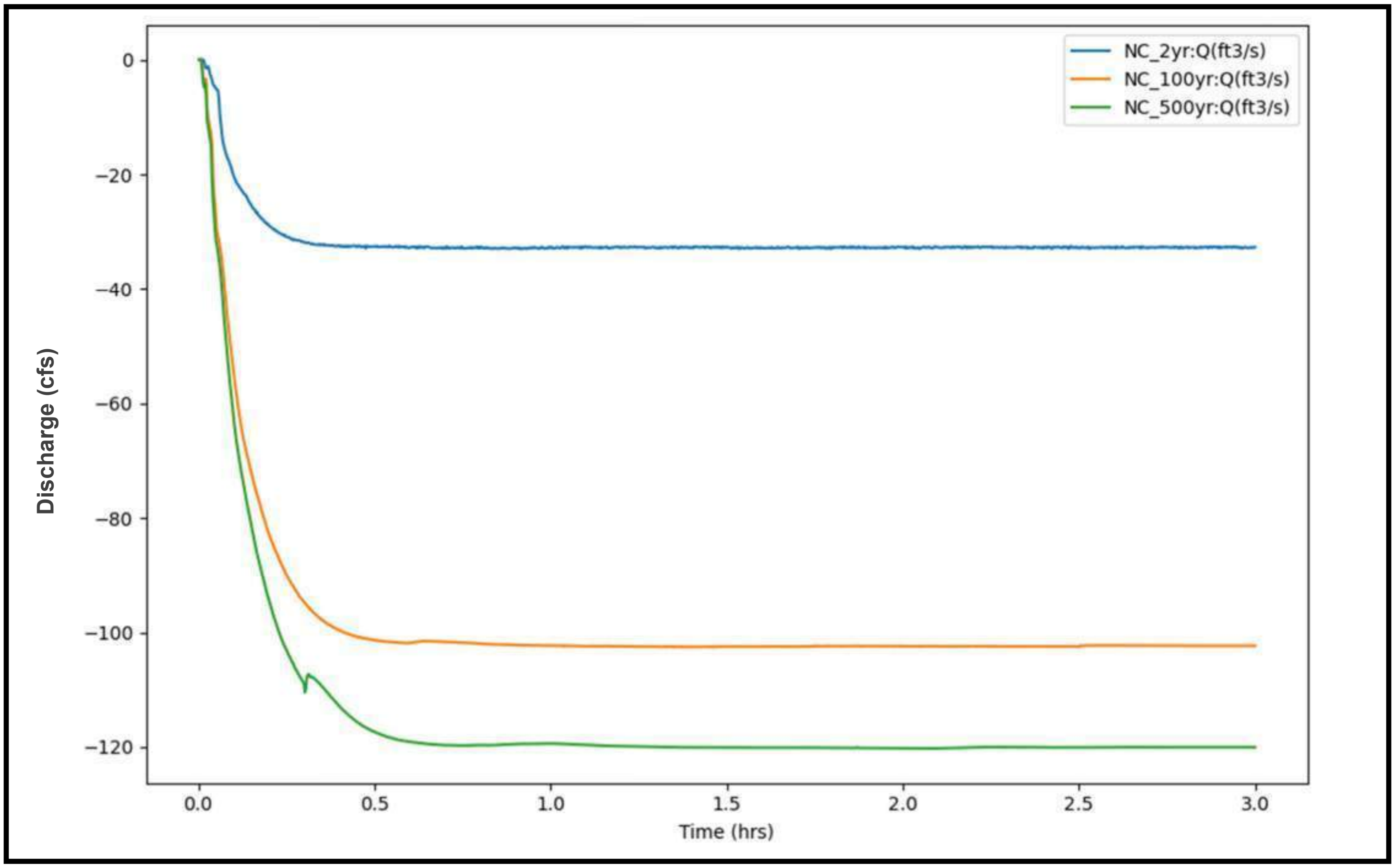
Natural Condition — Monitor Line 3 Flow vs. Time Plot



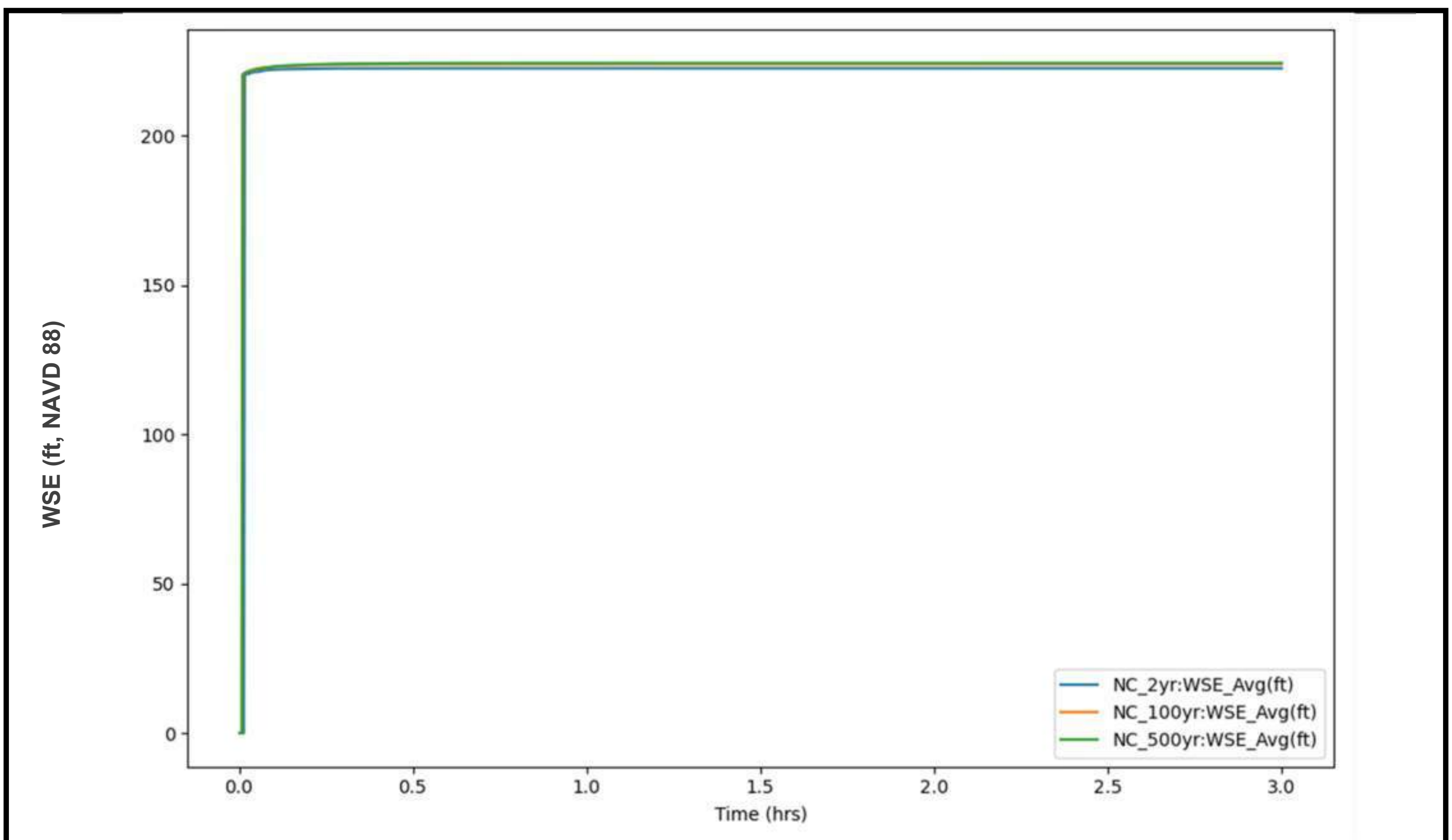
Natural Condition —Monitor Line 3 WSE vs. Time Plot



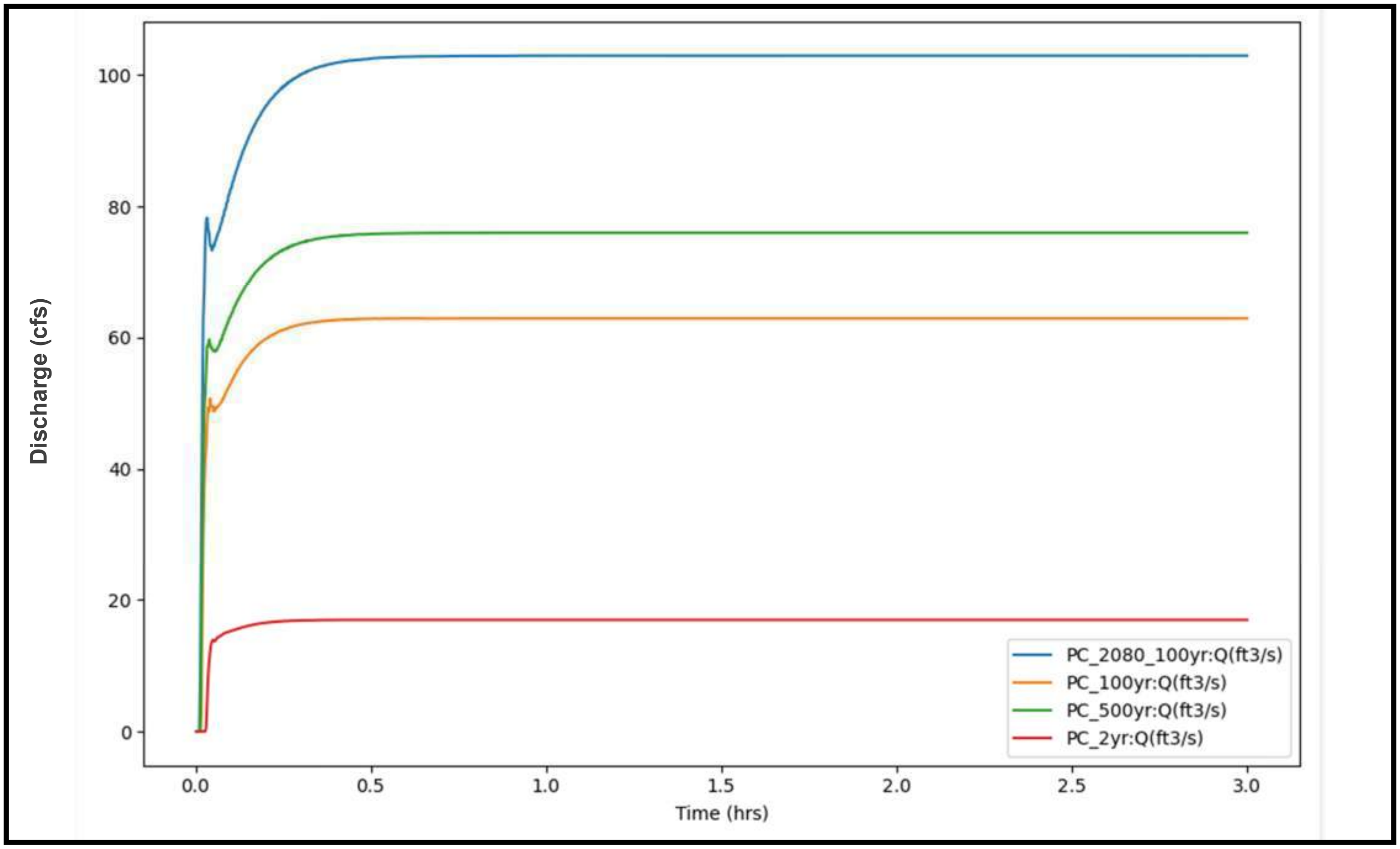
Natural Condition — Monitor Line 4 Flow vs. Time Plot



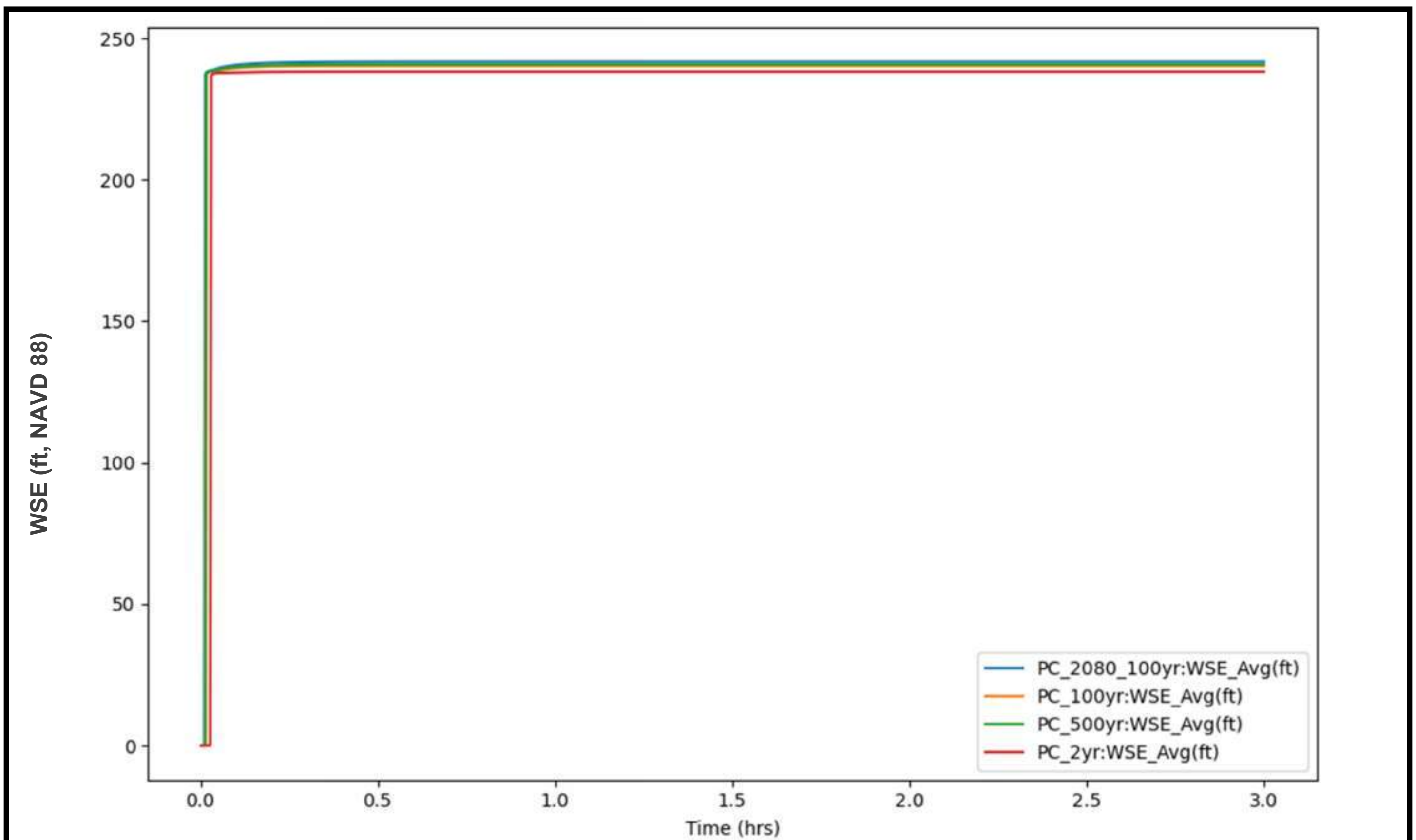
Natural Condition —Monitor Line 4 WSE vs. Time Plot



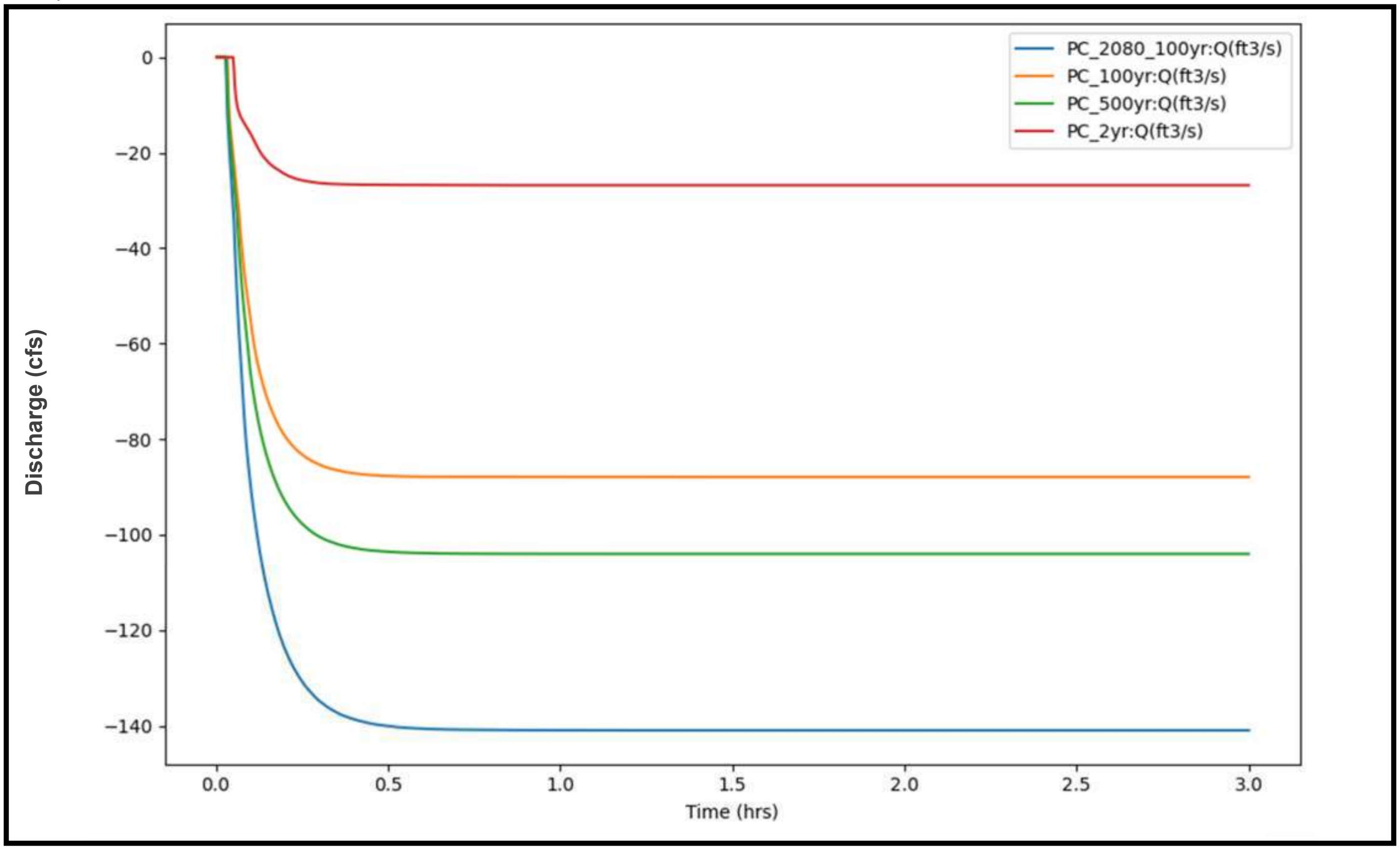
Proposed Condition — Monitor Line 1 Flow vs. Time Plot



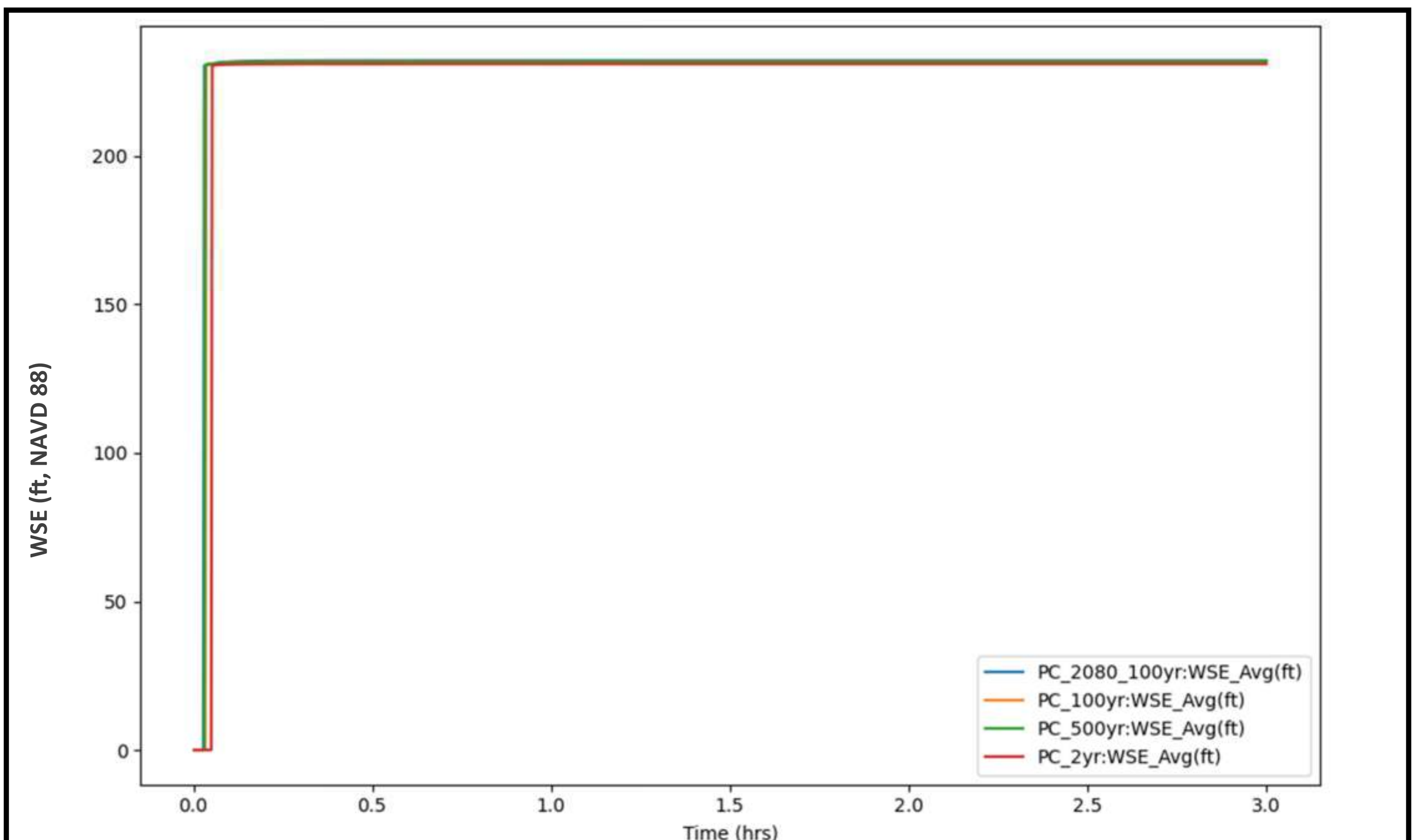
Proposed Condition —Monitor Line 1 WSE vs. Time Plot



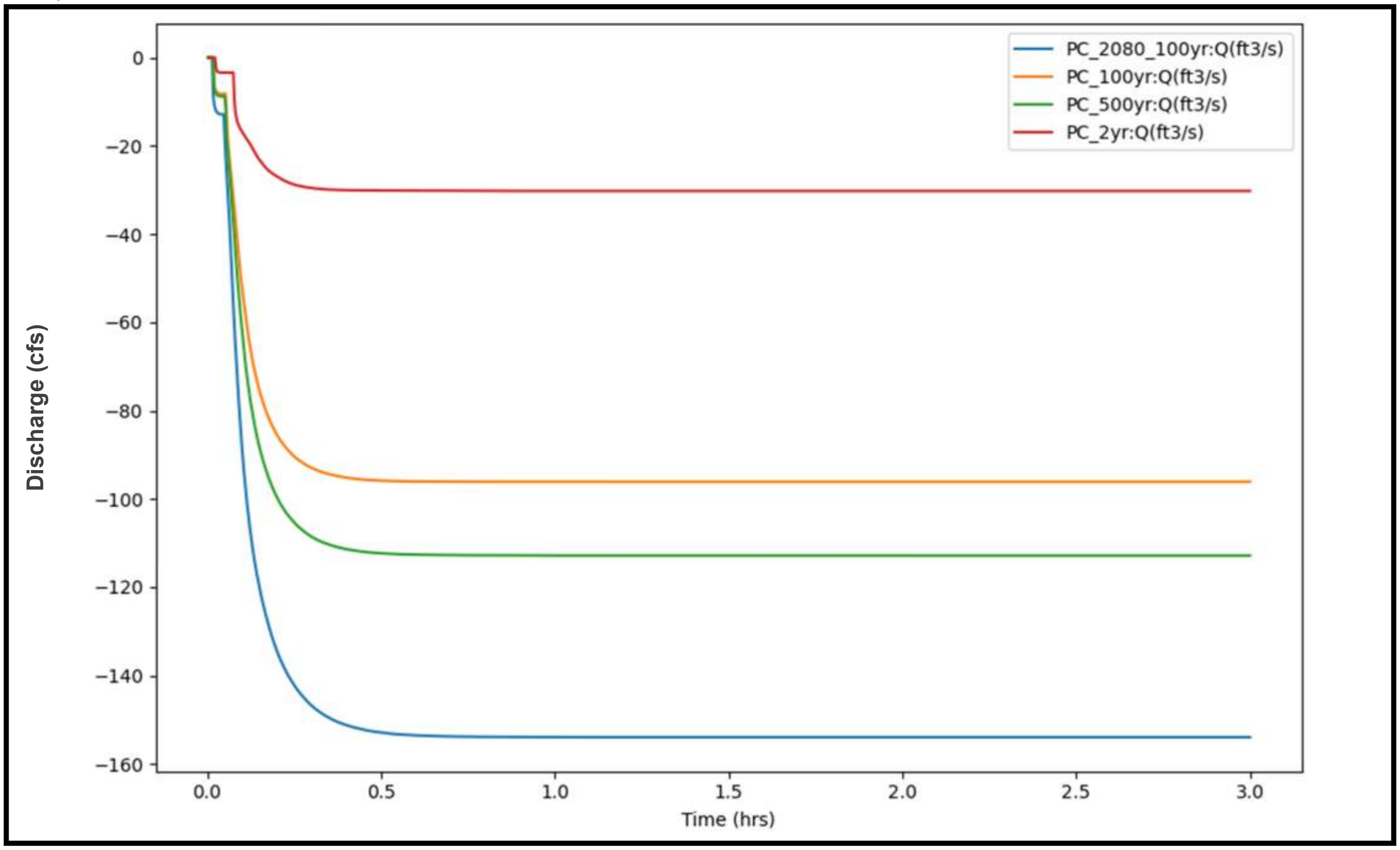
Proposed Condition — Monitor Line 2 Flow vs. Time Plot



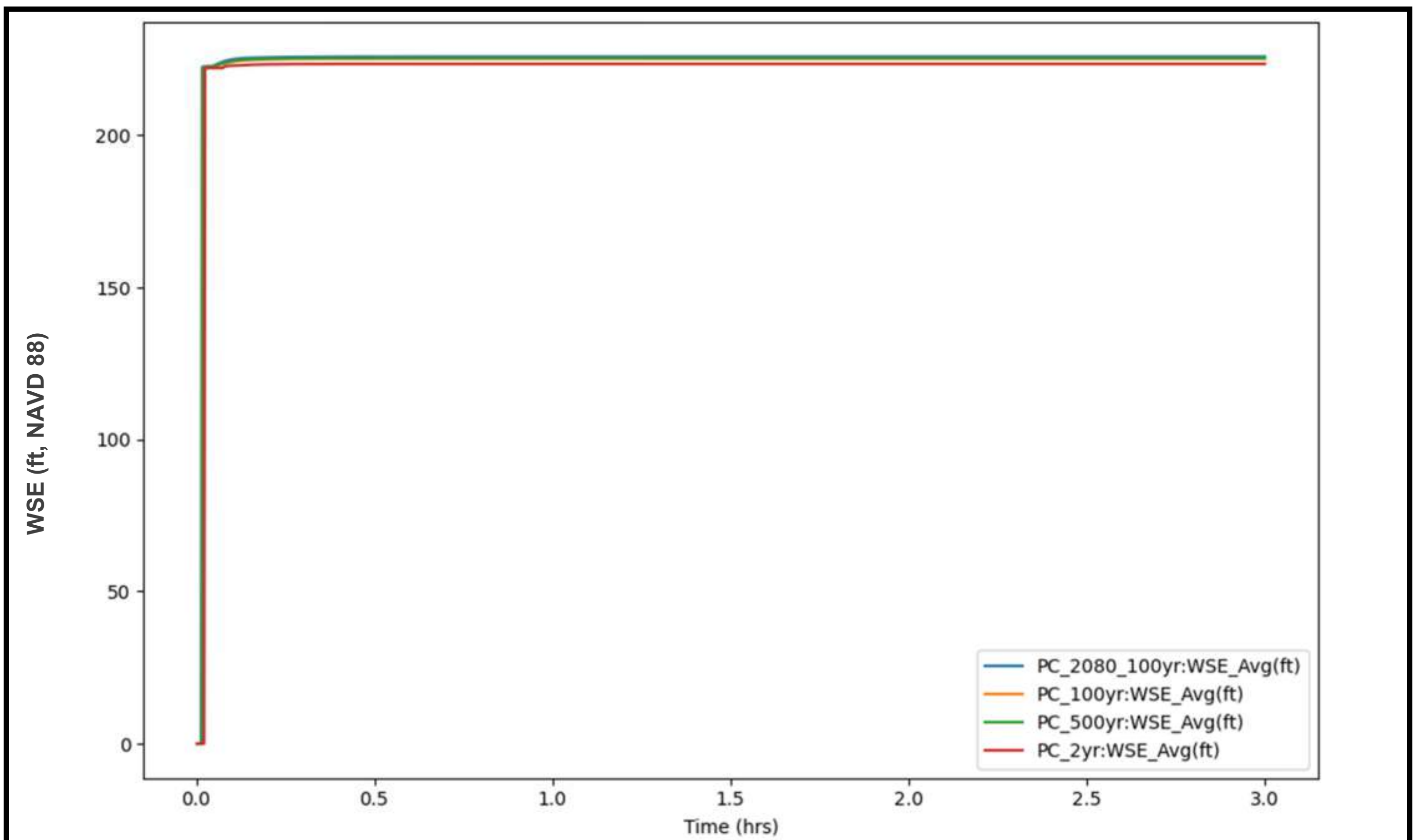
Proposed Condition —Monitor Line 2 WSE vs. Time Plot



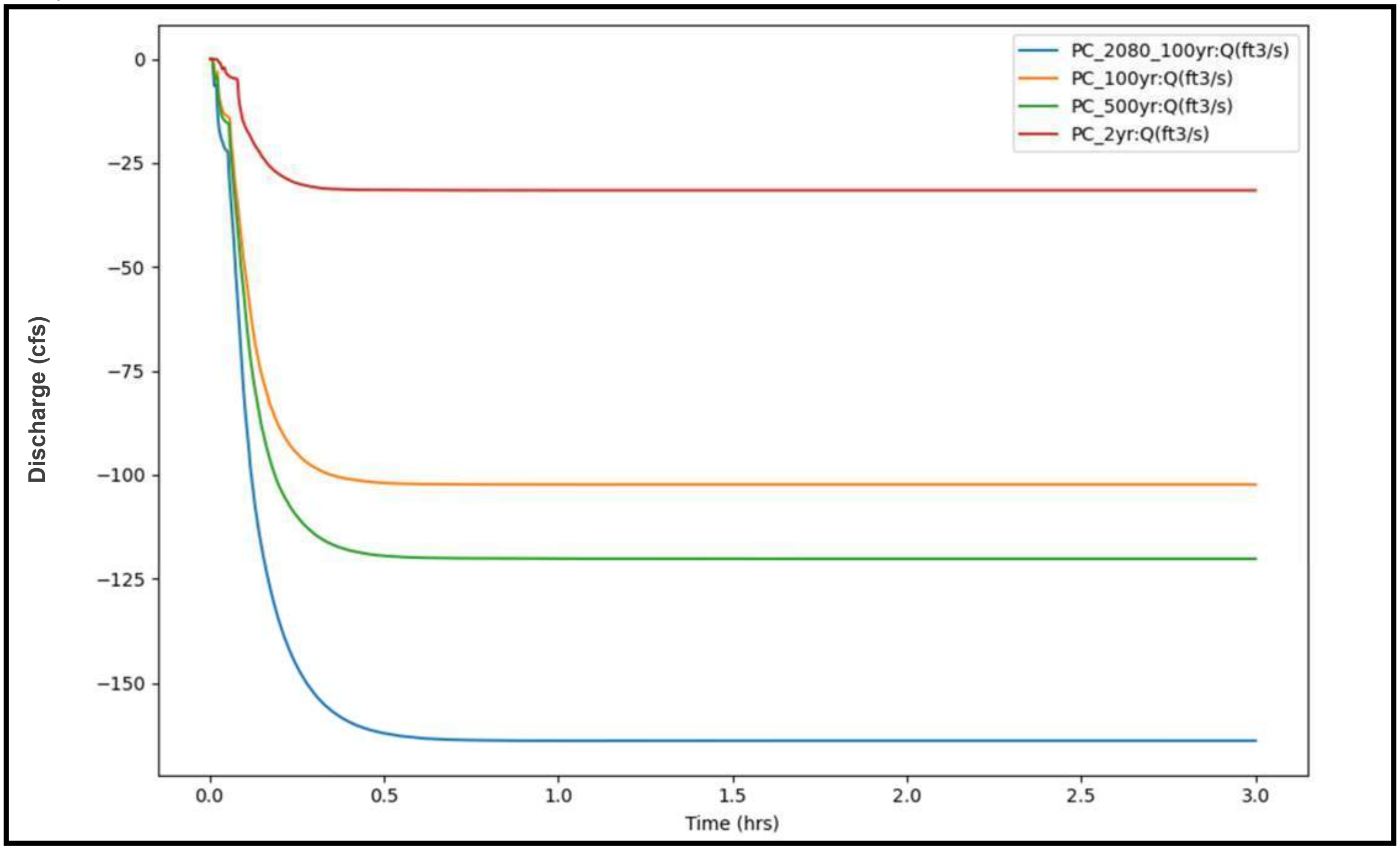
Proposed Condition — Monitor Line 3 Flow vs. Time Plot



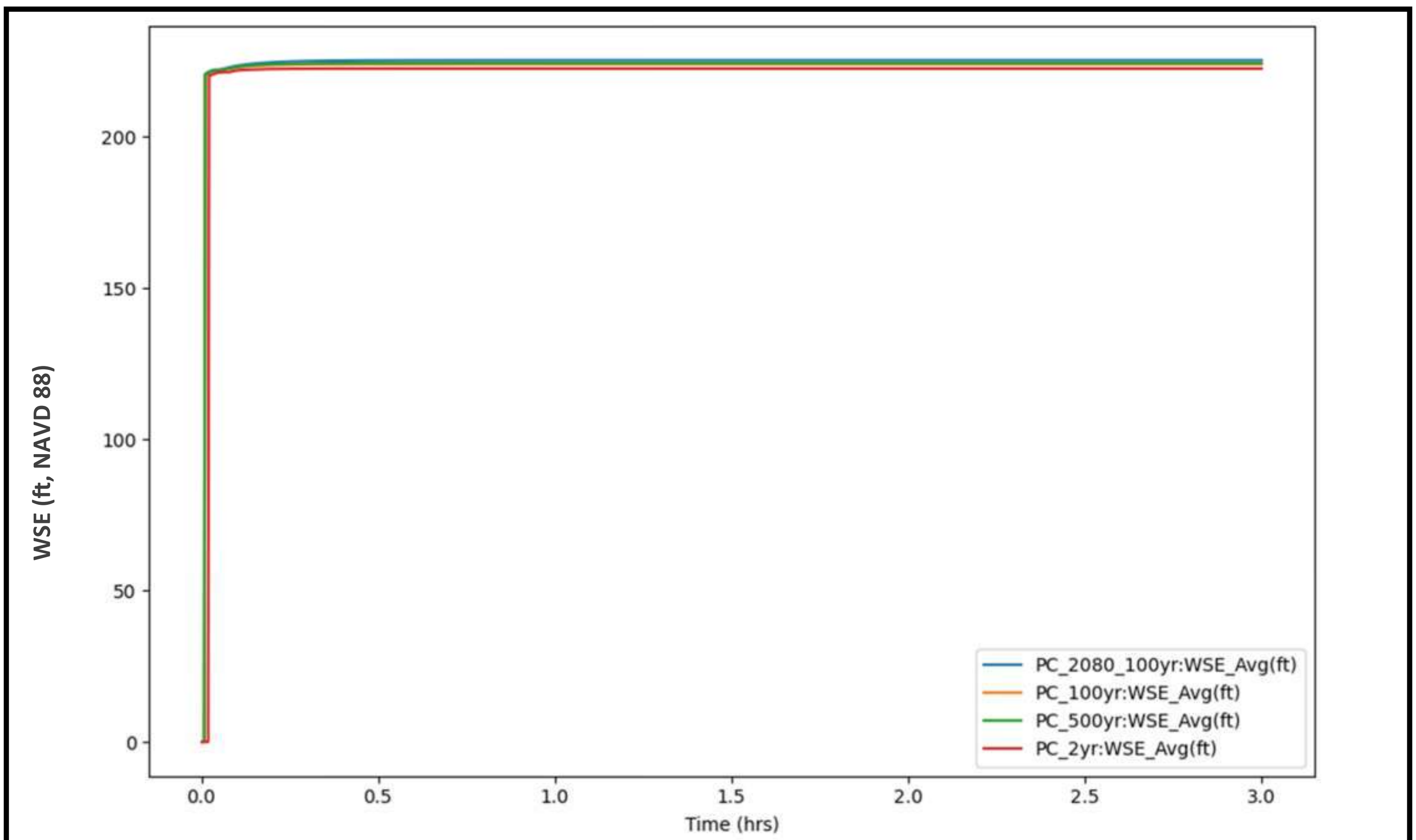
Proposed Condition —Monitor Line 3 WSE vs. Time Plot



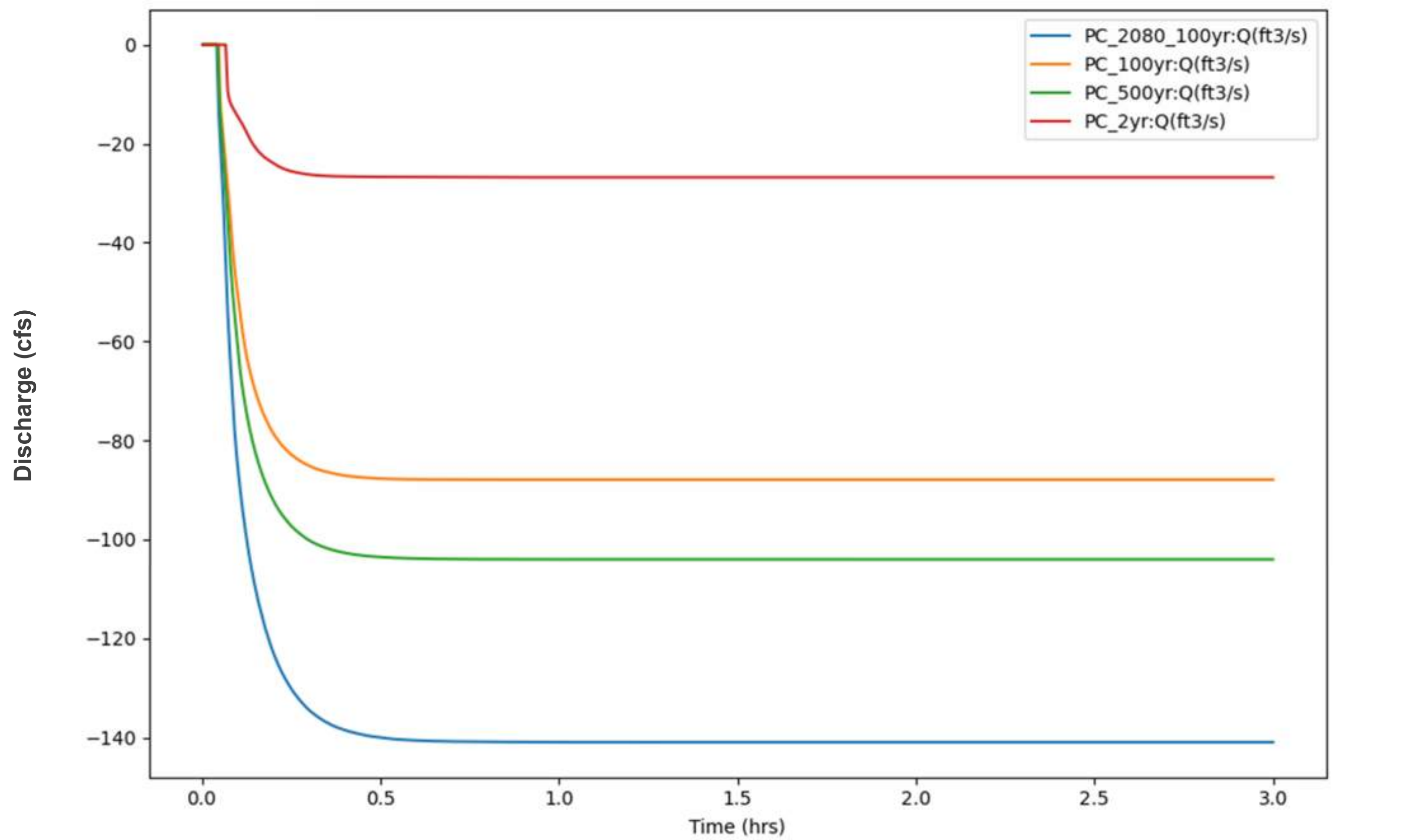
Proposed Condition — Monitor Line 4 Flow vs. Time Plot



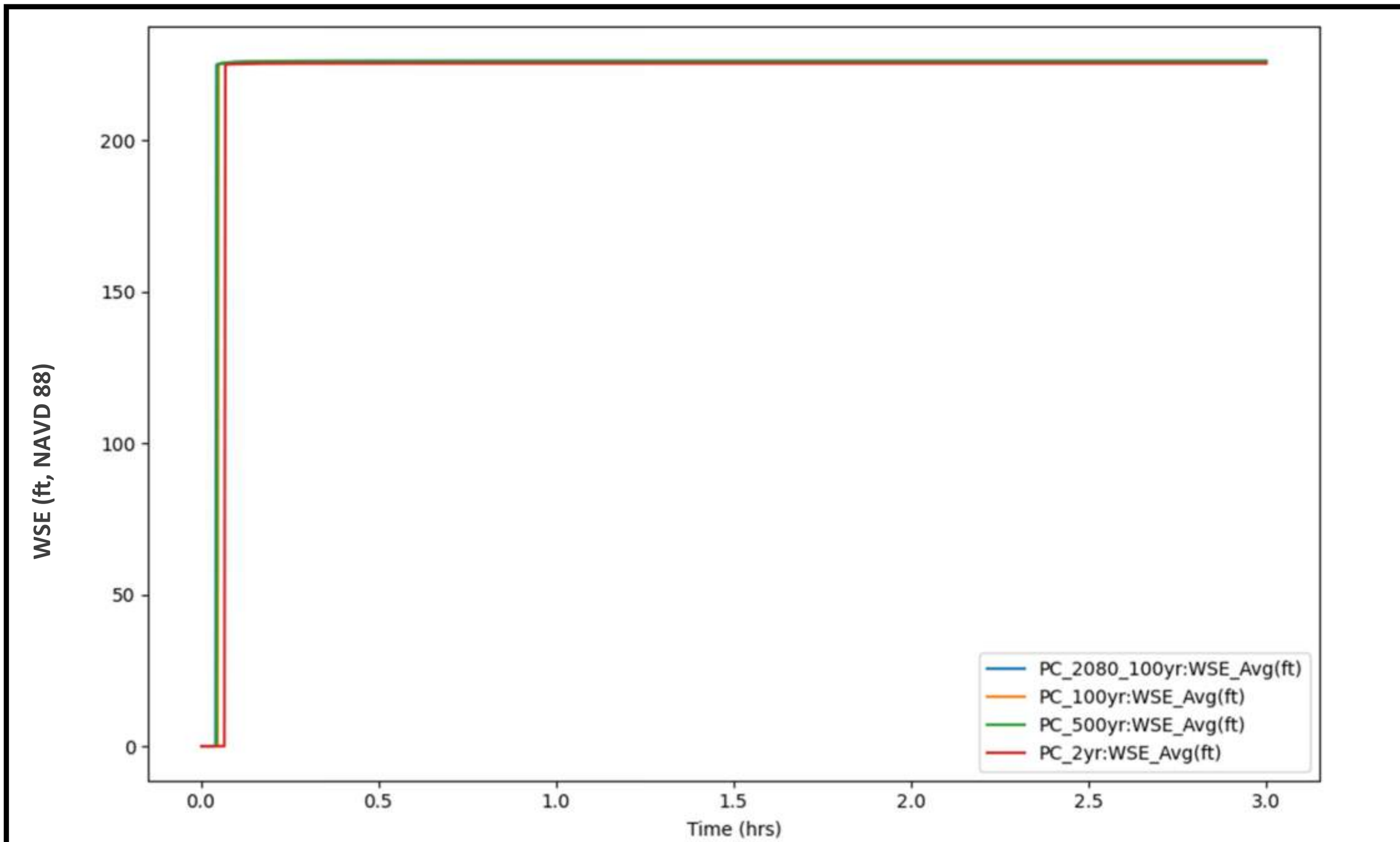
Proposed Condition —Monitor Line 4 WSE vs. Time Plot



Proposed Condition — Monitor Line 5 Flow vs. Time Plot



Proposed Condition —Monitor Line 5 WSE vs. Time Plot



Appendix J: Reach Assessment

There is no reach assessment for Johnson Creek to Liberty Bay at SR 3 MP 52.21.

Appendix K: Scour Calculations *(FHD ONLY)*

Scour calculations will be provided at the FHD for Johnson Creek to Liberty Bay at SR 3 MP 52.21.

Appendix L: Floodplain Analysis *(FHD ONLY)*

Floodplain Analysis will be provided at the FHD for Johnson Creek to Liberty Bay at SR 3 MP 52.21.

Appendix M: Hydrology

MGS FLOOD
PROJECT REPORT

Program Version: MGSFlood 4.55
Program License Number: 200410003
Project Simulation Performed on: 01/20/2022 9:56 AM
Report Generation Date: 01/20/2022 12:12 PM

Input File Name:	991744_JohnsonToLibertyBay_v2.fld
Project Name:	991744 Johnson Creek to Liberty Bay - Version 2
Analysis Title:	Flood Frequency Analysis
Comments:	Breaks down Basin 1 into subbasins

PRECIPITATION INPUT

Computational Time Step (Minutes): 15

Extended Precipitation Time Series Selected
Climatic Region Number: 4

Full Period of Record Available used for Routing
Precipitation Station : 95004405 Puget West 44 in_5min 10/01/1939-10/01/2097
Evaporation Station : 951044 Puget West 44 in MAP
Evaporation Scale Factor : 0.750

HSPF Parameter Region Number: 1
HSPF Parameter Region Name : USGS Default

********** Default HSPF Parameters Used (Not Modified by User) ***************

********************** WATERSHED DEFINITION ***********************

Predevelopment/Post Development Tributary Area Summary

	Predeveloped	Post Developed
Total Subbasin Area (acres)	388.437	388.427
Area of Links that Include Precip/Evap (acres)	0.000	0.000
Total (acres)	388.437	388.427

---------------------SCENARIO: PREDEVELOPED
Number of Subbasins: 5

---------- Subbasin : Subbasin 1a ----------

-------Area (Acres) --------	
Till Forest	6.270
Till Pasture	0.430
Till Grass	20.590
Outwash Forest	121.310
Outwash Pasture	0.220
Outwash Grass	109.630
Wetland	6.250
Impervious	52.390
Subbasin Total	317.090

---------- Subbasin : Subbasin 1b ----------

-------Area (Acres) --------	
Till Forest	6.460
Till Grass	5.520
Outwash Forest	14.340
Outwash Grass	12.340
Subbasin Total	38.660

---------- Subbasin : Subbasin 1c ----------

-------Area (Acres) --------	
Till Forest	1.863
Till Grass	0.695
Outwash Forest	0.359
Outwash Grass	0.261
Subbasin Total	3.177

---------- Subbasin : Subbasin 1d ----------

-------Area (Acres) --------	
Outwash Forest	10.170
Outwash Grass	4.660
Subbasin Total	14.830

---------- Subbasin : Subbasin 1e ----------

-------Area (Acres) --------	
Outwash Forest	10.940
Outwash Pasture	0.170
Outwash Grass	3.570
Subbasin Total	14.680

---------------------SCENARIO: POSTDEVELOPED

Number of Subbasins: 5

---------- Subbasin : Subbasin 1a ----------

-------Area (Acres) --------	
Till Forest	6.270
Till Pasture	0.430
Till Grass	20.590
Outwash Forest	121.310
Outwash Pasture	0.220
Outwash Grass	109.630
Wetland	6.250
Impervious	52.390
Subbasin Total	317.090

---------- Subbasin : Subbasin 1b ----------

-------Area (Acres) --------	
Till Forest	0.010
Till Grass	5.520
Outwash Forest	0.630
Outwash Grass	12.340
Impervious	20.150
Subbasin Total	38.650

---------- Subbasin : Subbasin 1c ----------

-------Area (Acres) --------	
Till Grass	0.695
Outwash Grass	0.261
Impervious	2.222
Subbasin Total	3.177

---------- Subbasin : Subbasin 1d ----------

-------Area (Acres) --------	
Outwash Grass	4.660
Impervious	10.170

Subbasin Total 14.830

---------- Subbasin : Subbasin 1e ----------
-------Area (Acres) --------
Outwash Pasture 0.170
Outwash Grass 3.570
Impervious 10.940

Subbasin Total 14.680

**************************** LINK DATA *******************************

----------------------SCENARIO: PREDEVELOPED
Number of Links: 1

Link Name: Johnson Creek to Liberty Bay
Link Type: Open Channel
Downstream Link: None

----------Left Overbank
Upper Sideslope (z) : 5.000
Upper Width (ft) : 16.000
Middle Sideslope (z) : 20.000
Middle Width (ft) : 82.000
Mannings n : 0.050

----------Main Channel
Lower Sideslope Left (z) : 3.000
Lower Width Left (ft) : 4.000
Lower Sideslope Right (z) : 1.000
Lower Width Right (ft) : 3.000
Mannings n : 0.035
Base Width (ft) : 3.5
Elevation (ft) : 219.50
Channel Slope (ft/ft) : 0.020
Channel Length (ft) : 1000.0

----------Right Overbank
Upper Sideslope (z) : 2.000
Upper Width (ft) : 33.500
Middle Sideslope (z) : 20.000
Middle Width (ft) : 12.500
Mannings n : 0.050

Hydraulic Conductivity (in/hr) : 0.0
Massmann Regression Used to Estimate Hydralic Gradient
Depth to Water Table (ft) : 100.0
Bio-Fouling Potential : Low
Maintenance : Average or Better

**************************** LINK DATA *******************************

----------------------SCENARIO: POSTDEVELOPED
Number of Links: 1

Link Name: Johnson Creek to Liberty Bay
Link Type: Open Channel
Downstream Link: None

----------Left Overbank
Upper Sideslope (z) : 5.000

Upper Width (ft) : 16.000
Middle Sideslope (z) : 20.000
Middle Width (ft) : 82.000
Mannings n : 0.050

----------Main Channel
Lower Sideslope Left (z) : 3.000
Lower Width Left (ft) : 4.000
Lower Sideslope Right (z) : 1.000
Lower Width Right (ft) : 3.000
Mannings n : 0.035
Base Width (ft) : 3.5
Elevation (ft) : 219.50
Channel Slope (ft/ft) : 0.020
Channel Length (ft) : 1000.0

----------Right Overbank
Upper Sideslope (z) : 2.000
Upper Width (ft) : 33.500
Middle Sideslope (z) : 20.000
Middle Width (ft) : 12.500
Mannings n : 0.050

Hydraulic Conductivity (in/hr) : 0.0
Massmann Regression Used to Estimate Hydralic Gradient
Depth to Water Table (ft) : 100.0
Bio-Fouling Potential : Low
Maintenance : Average or Better

**********************FLOOD FREQUENCY AND DURATION STATISTICS*******************

---------------------SCENARIO: PREDEVELOPED
Number of Subbasins: 5
Number of Links: 1

---------------------SCENARIO: POSTDEVELOPED
Number of Subbasins: 5
Number of Links: 1

**************Groundwater Recharge Summary ****************
Recharge is computed as input to Perlnd Groundwater Plus Infiltration in Structures

Total Predeveloped Recharge During Simulation

Model Element	Recharge Amount (ac-ft)
Subbasin: Subbasin 1a	86697.640
Subbasin: Subbasin 1b	11261.670
Subbasin: Subbasin 1c	649.986
Subbasin: Subbasin 1d	5064.658
Subbasin: Subbasin 1e	4957.173
Link: Johnson Creek to Lib	0.000
Total:	108631.100

Total Post Developed Recharge During Simulation

Model Element	Recharge Amount (ac-ft)
Subbasin: Subbasin 1a	86697.640
Subbasin: Subbasin 1b	5657.046
Subbasin: Subbasin 1c	186.954
Subbasin: Subbasin 1d	1800.532
Subbasin: Subbasin 1e	1445.910
Link: Johnson Creek to Lib	0.000
Total:	95788.090

Total Predevelopment Recharge is Greater than Post Developed

Average Recharge Per Year, (Number of Years= 158)
Predeveloped: 687.539 ac-ft/year, Post Developed: 606.254 ac-ft/year

*************Water Quality Facility Data ***************

---------------------SCENARIO: PREDEVELOPED

Number of Links: 1

********** Link: Johnson Creek to Liberty Bay **********

Infiltration/Filtration Statistics--------------------
Inflow Volume (ac-ft): 36467.49
Inflow Volume Including PPT-Evap (ac-ft): 36467.49
Total Runoff Infiltrated (ac-ft): 0.00, 0.00%
Total Runoff Filtered (ac-ft): 0.00, 0.00%
Primary Outflow To Downstream System (ac-ft): 36570.16
Secondary Outflow To Downstream System (ac-ft): 0.00
Volume Lost to ET (ac-ft): 0.00
Percent Treated (Infiltrated+Filtered+ET)/Total Volume: 0.00%

---------------------SCENARIO: POSTDEVELOPED

Number of Links: 1

********** Link: Johnson Creek to Liberty Bay **********

Infiltration/Filtration Statistics--------------------
Inflow Volume (ac-ft): 57343.20
Inflow Volume Including PPT-Evap (ac-ft): 57343.20
Total Runoff Infiltrated (ac-ft): 0.00, 0.00%
Total Runoff Filtered (ac-ft): 0.00, 0.00%
Primary Outflow To Downstream System (ac-ft): 57512.13
Secondary Outflow To Downstream System (ac-ft): 0.00
Volume Lost to ET (ac-ft): 0.00
Percent Treated (Infiltrated+Filtered+ET)/Total Volume: 0.00%

*************Compliance Point Results ***************

Scenario Predeveloped Compliance Link: Johnson Creek to Liberty Bay
Scenario Postdeveloped Compliance Link: Johnson Creek to Liberty Bay

***** Point of Compliance Flow Frequency Data *****
Recurrence Interval Computed Using Gringorten Plotting Position

Predevelopment Runoff		Postdevelopment Runoff	
Tr (Years)	Discharge (cfs)	Tr (Years)	Discharge (cfs)
2-Year	27.115	2-Year	45.458
5-Year	36.834	5-Year	61.171
10-Year	47.823	10-Year	75.811
25-Year	62.100	25-Year	96.570
50-Year	74.733	50-Year	109.786
100-Year	87.556	100-Year	113.537
200-Year	94.633	200-Year	123.405
500-Year	103.839	500-Year	136.672

** Record too Short to Compute Peak Discharge for These Recurrence Intervals

MGS FLOOD
PROJECT REPORT

Program Version: MGSFlood 4.55
Program License Number: 200410003
Project Simulation Performed on: 01/25/2022 8:52 AM
Report Generation Date: 01/25/2022 8:53 AM

Input File Name:	991744_JohnsonToLibertyBay_SB2_SB3.fld
Project Name:	991744 Johnson Creek to Liberty Bay - SB2 and SB3
Analysis Title:	Flood Frequency Analysis - Subbasin 2 and 3
Comments:	Subbasins 2 (Predeveloped) and 3 (Post Developed

PRECIPITATION INPUT

Computational Time Step (Minutes): 15

Extended Precipitation Time Series Selected
Climatic Region Number: 4

Full Period of Record Available used for Routing
Precipitation Station : 95004405 Puget West 44 in_5min 10/01/1939-10/01/2097
Evaporation Station : 951044 Puget West 44 in MAP
Evaporation Scale Factor : 0.750

HSPF Parameter Region Number: 1
HSPF Parameter Region Name : USGS Default

********** Default HSPF Parameters Used (Not Modified by User) ***************

********************** WATERSHED DEFINITION ***********************

Predevelopment/Post Development Tributary Area Summary

	Predeveloped	Post Developed
Total Subbasin Area (acres)	28.780	16.420
Area of Links that Include Precip/Evap (acres)	0.000	0.000
Total (acres)	28.780	16.420

----------------------SCENARIO: PREDEVELOPED
Number of Subbasins: 1

---------- Subbasin : Subbasin 2 ----------

	-------Area (Acres) --------
Till Forest	0.260
Till Grass	0.350
Outwash Forest	11.660
Outwash Grass	13.420
Impervious	3.090
Subbasin Total	28.780

----------------------SCENARIO: POSTDEVELOPED
Number of Subbasins: 1

---------- Subbasin : Subbasin 3 ----------

	-------Area (Acres) --------
Outwash Grass	8.480
Impervious	7.940
Subbasin Total	16.420

************************* LINK DATA *******************************

----------------------SCENARIO: PREDEVELOPED
Number of Links: 0

************************* LINK DATA *******************************

----------------------SCENARIO: POSTDEVELOPED
Number of Links: 0

**********************FLOOD FREQUENCY AND DURATION STATISTICS*******************

----------------------SCENARIO: PREDEVELOPED
Number of Subbasins: 1
Number of Links: 0

----------------------SCENARIO: POSTDEVELOPED
Number of Subbasins: 1
Number of Links: 0

*************Groundwater Recharge Summary ***************
Recharge is computed as input to Perlnd Groundwater Plus Infiltration in Structures

Total Predeveloped Recharge During Simulation

Model Element	Recharge Amount (ac-ft)
Subbasin: Subbasin 2	9019.556
Total:	9019.556

Total Post Developed Recharge During Simulation

Model Element	Recharge Amount (ac-ft)
Subbasin: Subbasin 3	3276.504
Total:	3276.504

Total Predevelopment Recharge is Greater than Post Developed
Average Recharge Per Year, (Number of Years= 158)
Predeveloped: 57.086 ac-ft/year, Post Developed: 20.737 ac-ft/year

*************Water Quality Facility Data ***************

----------------------SCENARIO: PREDEVELOPED

Number of Links: 0

----------------------SCENARIO: POSTDEVELOPED

Number of Links: 0

*************Compliance Point Results ***************

Scenario Predeveloped Compliance Subbasin: Subbasin 2

Scenario Postdeveloped Compliance Subbasin: Subbasin 3

***** Point of Compliance Flow Frequency Data *****
Recurrence Interval Computed Using Gringorten Plotting Position

Predevelopment Runoff Postdevelopment Runoff

Tr (Years)	Discharge (cfs)	Tr (Years)	Discharge (cfs)
2-Year	1.434	2-Year	3.427
5-Year	2.108	5-Year	4.526
10-Year	2.893	10-Year	5.231
25-Year	3.808	25-Year	6.371
50-Year	5.065	50-Year	7.918
100-Year	6.193	100-Year	8.197
200-Year	6.702	200-Year	8.436
500-Year	7.355	500-Year	8.758

** Record too Short to Compute Peak Discharge for These Recurrence Intervals

Jacobs

	CLIENT: WSDOT			DATE:	3/15/2022
JOB TITLE:	WSDOT NW Region Fish Passage - PHD - SR3 Unnamed to Dyes Inlet - 991744	BY:	BW, EIT	JOB #:	W3Y05003 | A.P4.EV.991744-2-2-2
SUBJECT:	Hydrology Model Input Computations	CHECKED:	TJ, PE	Sheet #:	1 of 2
Topic:	USGS Regression Equations - Basin 1				

Flood Q Regression Tool. Use to estimate flood discharge in Washington State at ungaged sites based on regional regression equations and user-determined basin characteristics.

DA = Drainage Area, in square miles; P = Average Basin Annual Precipitation, in inches (from PRISM data set, years 1981-2010); CAN = Percent canopy cover (NLCD 2001); AEP = Annual Exceedance Probability; Qu = Flood Discharge, in cubic feet per second at ungaged site for the indicated AEP; PI_L, PI_U= Predition Intervals (L=Lower and U=Upper)

Instructions for using the Flood Q Tool to estimate Flood Discharges at Ungaged Sites using the regional regression equations

Steps	Instructions
1	Select the Regression Region below from the List Box
2	Determine the drainage area, *DA* and the Annual Precipitation, *P* for the ungage drainage basin. If you pick Regression Region 1 or 2, determine the percent canopy cover, *CAN*.
3	Enter these basin characteristic values in the green-shade cells. If the cell changes to red, than the value is outside the range of valid values for this regression. Valid value range listed to the right of the green cells.
4	Rows 23-30 will have the results. Estimated flood discharge, Qu, will be found in column O and the 90% prediction limits for these flood discharges will be found in columns R and T.

Regression Region 1
Regression Region 2
Regression Region 3
Regression Region 4

User determined basin characteristics for ungaged site

				Range of values that are valid for the regression
Selected Region:		Regression Region 3		
Drainage Area, *DA*	=	0.60625	square mile	0.08 - 2605
Annual Precipitation, *P*	=	40.80	inches	33.29 - 168.0
Percent Canopy, *CAN*	=	33	%	value not used in regressior

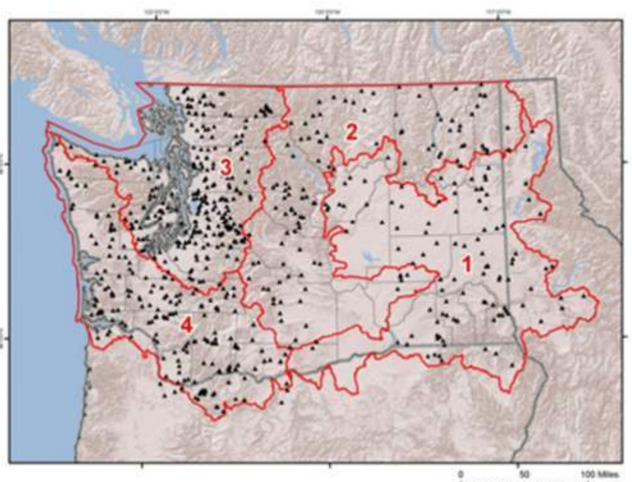
Selected Region: Regression Region 3

Estimate of indicated flood discharge for Regression Region 3 using regional regression equations

AEP		*Q_u, ft³/s	Prediction Intervals, 90% confidence level: PI_L, in ft³/s	PI_U, in ft³/s
0.5	=	12.3	6.1	24.7
0.2	=	19.8	9.6	40.7
0.1	=	24.8	11.9	51.6
0.04	=	31.5	14.5	68.4
0.02	=	36.4	16.3	81.5
0.01	=	41.8	18.3	95.5
0.005	=	47.1	19.8	111.8
0.002	=	54.5	21.9	135.4

*rounded to 3 significant figures

Regression Regions in Washington State



Flood Q Regression Tool. Use to estimate flood discharge in Washington State at ungaged sites based on regional regression equations and user-determined basin characteristics.

DA = Drainage Area, in square miles; P = Average Basin Annual Precipitation, in inches (from PRISM data set, years 1981-2010); CAN = Percent canopy cover (NLCD 2001); AEP = Annual Exceedance Probability; Qu = Flood Discharge, in cubic feet per second at ungaged site for the indicated AEP; PI_L, PI_U= Predition Intervals (L=Lower and U=Upper)

Instructions for using the Flood Q Tool to estimate Flood Discharges at Ungaged Sites using the regional regression equations

Steps	Instructions
1	Select the Regression Region below from the List Box
2	Determine the drainage area, *DA* and the Annual Precipitation, *P* for the ungage drainage basin. If you pick Regression Region 1 or 2, determine the percent canopy cover, *CAN*.
3	Enter these basin characteristic values in the green-shade cells. If the cell changes to red, than the value is outside the range of valid values for this regression. Valid value range listed to the right of the green cells.
4	Rows 23-30 will have the results. Estimated flood discharge, Qu, will be found in column O and the 90% prediction limits for these flood discharges will be found in columns R and T.

Regression Region 1
Regression Region 2
Regression Region 3
Regression Region 4

User determined basin characteristics for ungaged site

Selected Region:		Regression Region 3	Range of values that are valid for the regression
Drainage Area, *DA*	=	0.67281 square mile	0.08 - 2605
Annual Precipitation, *P*	=	40.80 inches	33.29 - 168.0
Percent Canopy, *CAN*	=	36 %	value not used in regression

Selected Region: Regression Region 3

Estimate of indicated flood discharge for Regression Region 3 using regional regression equations

			Prediction Intervals, 90% confidence level	
AEP		*Q_u, ft³/s	PI_L, in ft³/s	PI_U, in ft³/s
0.5	=	13.6	6.8	27.3
0.2	=	21.7	10.6	44.5
0.1	=	27.3	13.1	56.7
0.04	=	34.5	15.9	74.8
0.02	=	40	17.9	89.5
0.01	=	45.9	20.1	104.8
0.005	=	51.7	21.8	122.7
0.002	=	59.9	24.1	148.7

*rounded to 3 significant figures

Regression Regions in Washington State